Energy Research and Development Division

FINAL PROJECT REPORT

SOLAR ENERGY AND THE MOJAVE DESERT TORTOISE

Appendices

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Solar Energy and the Mojave Desert Tortoise: Modeling Impacts and Mitigation is the final report for the Desert Tortoise Spatial Decision Support System project (contract number CEC-PIR-10-048) conducted by the University of Redlands, Redlands Institute and the U.S. Fish and Wildlife Service, Desert Tortoise Recovery Office. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

Increasing energy production from renewable sources is a strategic priority for California and the nation. Large, utility-scale solar developments have been proposed for the Mojave Desert to help achieve this goal, and many more are anticipated. However, such developments have extensive land and water requirements, and they can have negative impacts on ecosystems and vulnerable species.

Protecting existing populations and habitat for the state and federally-listed Mojave desert tortoise, while implementing recovery actions to improve habitat quality, is also a high priority. Tools are needed to quantify the impacts of various developments and to determine the set of recovery actions and mitigation measures to compensate for those impacts.

To address this need, the University of Redlands and the U.S. Fish and Wildlife Service's Desert Tortoise Recovery Office developed a Geographic Information Systems-based decision support system. The system modeled the interrelationships among existing threats and their contributions to population change, and evaluated how those relationships are affected by proposed recovery actions. However, the original version did not explicitly incorporate potential changes in underlying threats, such as those resulting from new solar energy development.

This project expanded the original system to support environmental review of new solar energy development projects. Improvements to system models, calculations, and technology enable users to conduct spatially-explicit and fully documented combined impacts analyses of solar projects, and evaluate mitigation options for the desert tortoise. This project also developed a Web-based portal, where users can input solar energy development project footprints and run new impact and mitigation calculations.

Agencies are using the system to assess the probable impacts of individual solar energy development projects on the desert tortoise and potential mitigation actions. This supports agencies in making better decisions to promote conservation, while reducing uncertainty and delays in the permitting process for the benefit of California's ratepayers.

Keywords: endangered species, decision support, desert tortoise, GIS, mitigation, spatial analysis, solar energy, threats assessment, recovery actions, uncertainty, sensitivity, impacts, siting, permitting

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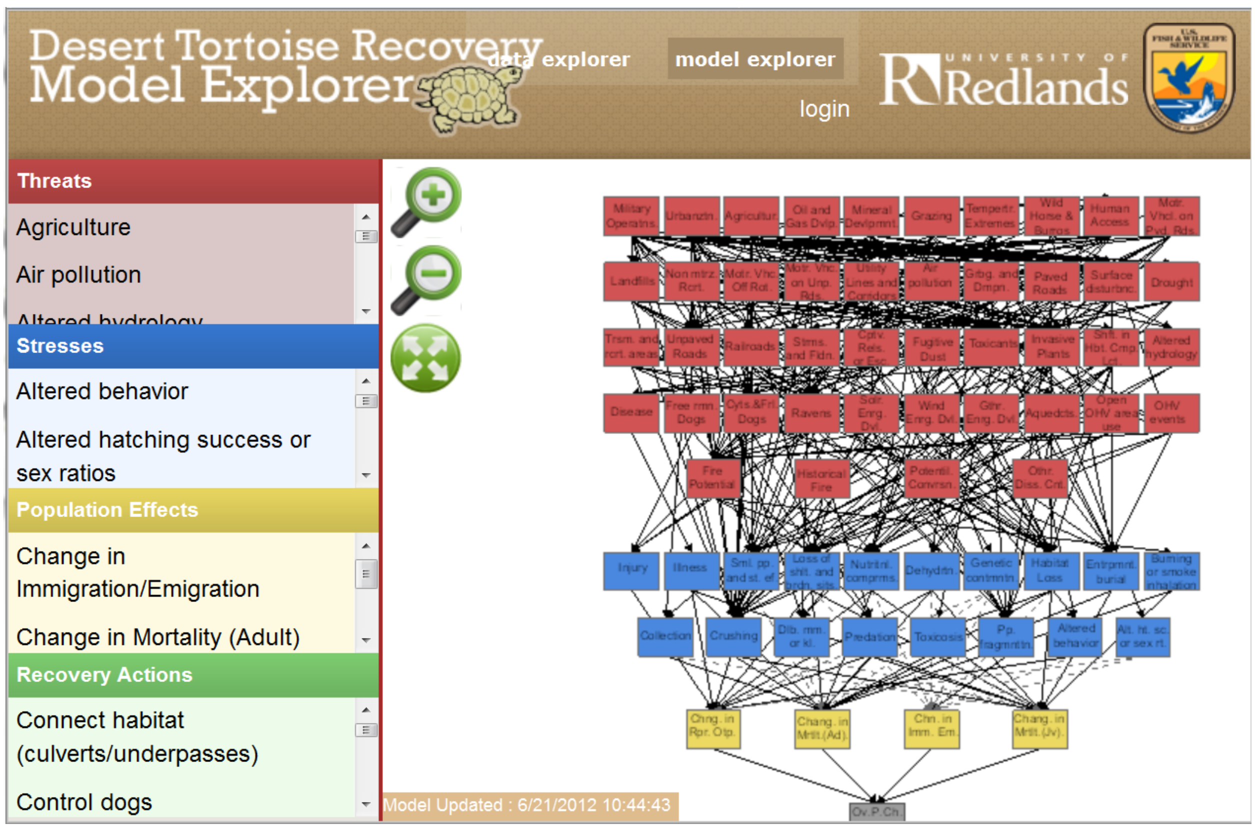
Appendix A: Entities in the Desert Tortoise Conceptual Model

The Desert Tortoise Conceptual Model describes entities such as threats, stresses, population effects, and recovery actions. This appendix provides a complete list of items in each entity as they were in the desert tortoise conceptual model in July 2012.

Definition of Entity Types (Darst et al 2013):

Entity Type	Definition
Threat	Proximate human activities that have caused, are causing, or may cause the destruction, degradation, or impairment of species (Salafsky and others 2008)
Stress	Degraded conditions or ‘‘symptoms’’ of the species that result from a threat (Salafsky and others 2008)
Population Effect	Change in mortality, reproductive output, or immigration or emigration in a population
Recovery Action	Conservation actions that are designed specifically to contribute to the recovery of at-risk species



Access this interactive representation at http://www.spatial.redlands.edu/dtro/modelexplorer

Threats (44)

THREAT NAME	THREAT DESCRIPTION
Agriculture	Farming of annual and perennial crops; hay/pasture and cultivated crops.
Air pollution	Increased levels of atmospheric pollution and nitrogen deposition related to increased human presence and combustion of fossil fuels resulting in increased particulate matter in the air and increase levels of soil nitrogen.
Altered hydrology	Modification of the occurrence, distribution, and movement of water, such that natural water transportation, storage and evaporation processes are affected.
Aqueducts	Channel or conduit constructed to convey water, typically a system of ditches, canals, and tunnels.
Captive Release or Escape	Release of captive-reared and/or wild-caught tortoises that have been in captivity.
Coyotes & Feral Dogs	Coyotes and feral dogs are subsidized by human activities; the elevated levels of predation are a stress on desert tortoise populations.
Disease	Harmful pathogens and other microbes that may or may not be endemic to the ecosystem or region but that are directly or indirectly introduced spread, or susceptibility is increased by humans and/or human activities. Upper respiratory tract disease as caused by Mycoplasma spp. is the best known disease pertinent to the desert tortoise; others include herpesvirus and Pasteruela testudinis.
Drought	Periods in which rainfall falls below the normal range of variation, which can result in desertification and limited water availability. Drought is a natural process, but one that can be exacerbated by human activities that influence climate change (Christensen et al. 2007). However, the stochastic (random) nature of this threat is beyond the scope of the SDSS to model at this time. We therefore represent this threat as a spatial constant in order to capture a baseline level of interaction with other threats or stresses.
Fire Potential	Potential for human or naturally caused fire in desert tortoise habitats.
Free-roaming Dogs	Domestic dogs that are not restrained by leashes or contained in fenced yards
Fugitive Dust	Airborne particulate matter containing toxicants released from anthropogenic sites such as mines, roads, construction, and other disturbances.
Garbage and Dumping	Refuse resulting from unauthorized dumping and littering or wind-blown accumulation.
Geothermal Energy Development	Development and production of geothermal energy
Grazing	Utilizing natural habitats for forage to support domestic livestock (i.e., cattle and sheep); typically use on public lands is authorized by allotments, animal unit months (cow/calf for cattle), forage availability, and season of use according to established Standards and Guidelines and allotment-specific objectives.

Historical Fire	Past human or naturally caused fire in desert tortoise habitats.
Human Access	Permission, liberty, or ability to enter, approach, or pass to and from a place from various points that facilitates both authorized and unauthorized land uses
Invasive Plants	Plants species not native to the ecosystem; <115 non-native plant species have been documented in the Mojave and Sonoran deserts, many are of Eurasian origin and have become common to abundant in the desert tortoise habitats due to historic and ongoing land disturbance.
Landfills	Authorized sites to take in household and industrial garbage and solid waste.
Military Operations	Military installations, training, and range exercises using explosives, military vehicles, urban simulation, etc.
Mineral Development	Exploring for, developing, and producing minerals and rocks, including ancillary facilities, leachate ponds, and mine tailings; metals, semi-metals, minerals, sand and gravel, coal etc.
Motor Vehicles Off Route	Self-propelled, wheeled vehicles (including cars, trucks, jeeps, motorcycles, and ATVs) illegally traveling cross-country or on closed routes.
Motor Vehicles on Paved Roads	Self propelled, wheeled vehicles on paved roads, including cars, trucks, jeeps, motorcycles, and all-terrain vehicles (ATVs).
Motor Vehicles on Unpaved Roads	Self propelled, wheeled vehicles on unpaved roads which are open and legal for motorized travel, including cars, trucks, jeeps, motorcycles, and all-terrain vehicles (ATVs).
Non-motorized Recreation	Outdoor activities that do not involve the use of motorized vehicles, such as primitive camping, hunting, target practice, hiking, picnicking, horseback riding, and biking.
OHV events	Large- or small-scale competitive races or non-competitive events involving up to thousands of motorcycles and other recreational off-highway vehicles
Oil and Gas Development	Development and production of oil and gas; wells and pipelines.
Open OHV area use	Open-use public land where off-highway vehicles can be ridden anywhere, includes travel on both open routes and cross-country travel within the designated open area.
Other Disease Contributors	Much remains unknown about anthropogenic factors which increase disease or disease susceptibility in desert tortoise populations
Paved Roads	Linear corridors that have been finished with asphalt or concrete, typically impervious, to support vehicular or other travel.
Potential Conversion	Privately-held parcels of land which contribute to fragmentation, potential habitat loss, and difficulty managing for tortoise conservation, especially within Tortoise Conservation Areas.
Railroads	Transportation mode of vehicles or cars on corridors of parallel steel tracks.
Ravens	Corvus corax; considered a human-subsidized predator of mostly hatchling and juvenile desert tortoises.
Shift in Habitat Composition/Loc	Potential changes in climate may cause or have already caused changes in species composition in desert tortoise habitats and shifts in habitat

ation	availability and usage. Shift in habitat composition and/or locations is a natural process, but one that can be exacerbated by human activities that influence climate change (Christensen et al. 2007). However, the stochastic (random) nature of this threat is beyond the scope of the SDSS to model at this time. We therefore represent this threat as a spatial constant in order to capture a baseline level of interaction with other threats or stresses.
Solar Energy Development	Development and production of solar energy; solar farms and ancillary facilities.
Storms and Flooding	Extreme precipitation and/or wind events or major shifts in seasonality of storms. Storms and Flooding are a natural process, but one that can be exacerbated by human activities that influence climate change (Christensen et al. 2007). However, the stochastic (random) nature of this threat is beyond the scope of the SDSS to model at this time. We therefore represent this threat as a spatial constant in order to capture a baseline level of interaction with other threats or stresses.
Surface disturbance	Disruption or removal of surface soil and/or vegetation.
Temperature Extremes	Periods in which temperatures exceed or go below the normal range of variation, including heat waves and cold spells. Temperature Extremes are a natural process, but one that can be exacerbated by human activities that influence climate change (Christensen et al. 2007). However, the stochastic (random) nature of this threat is beyond the scope of the SDSS to model at this time. We therefore represent this threat as a spatial constant in order to capture a baseline level of interaction with other threats or stresses.
Tourism and recreation areas	Small-scale, dispersed developments such as golf courses, campgrounds, visitor's centers, RV parks, and rest stops.
Toxicants	Air- and water-borne toxic substances from mine tailings, illegal dumping of hazardous wastes, garbage/litter, and toxic spills.
Unpaved Roads	Dirt or gravel secondary or tertiary roads, often labeled as accessible to 4-wheel drive vehicles only (includes BLM's open OHV routes).
Urbanization	Urban and suburban development and associated infrastructure; NLCD data include developed/urban landscapes from high density, entirely impervious surfaces, to areas of single family homes, to golf courses.
Utility Lines and Corridors	Utility corridors and lines including transmission and power lines and poles, and oil and gas pipelines.
Wild Horse & Burros	Unbranded and unclaimed horses and burros on public lands protected under the Wild Free-roaming Horses and Burros Act of 1071 (PL 92-195); herd management areas are generally established as a means of maintaining healthy, genetically viable populations and determining appropriate management levels within a given area or range of the herd.
Wind Energy Development	Development and production of wind energy; wind farms and ancillary facilities

Stresses (18)

STRESS NAME	DESCRIPTION
Altered behavior	Sublethal effects of changes in environmental conditions which effect tortoise behavior, such as fewer hours within the temperature range suitable for mating, feeding, etc.
Altered hatching success or sex ratios	Reduced reproductive output of females and/or altered sex ratios in temperature-sex-determined animals
Burning or smoke inhalation	Mortality due to fire or excessive heat; mortality due to breathing smoke caused by wildfire.
Collection	Removal of desert tortoises by humans from the wild for commercial, recreational, or cultural purposes.
Crushing	Mortality due to excessive force or weight being exerted on animal either above or below ground.
Dehydration	Abnormal depletion of body fluids; potentially due to effects of drought or malnutrition.
Deliberate maiming or killing	Mortality due to deliberate maiming or killing of desert tortoises by humans with malicious intent or to obtain animal products.
Entrapment/burial	Mortality due to animal being caught or trapped in a way that precludes movement or escape.
Genetic contamination	Gene flow into a wild population that has been facilitated by the release of captive tortoises or by translocation of tortoises from a distant location.
Habitat Loss	Land area subject to the complete or absolute removal of elements necessary for desert tortoise occupation (i.e., grading or paving of the landscape, removing all feeding, sheltering or breeding resources) or that falls below other identified thresholds of habitat quality required to support desert tortoises.
Illness	Mortality or sublethal effects due to disordered or weakened condition caused by an illness
Injury	Sublethal effects of bodily hurt, damage, or loss.
Loss of shelter and breeding sites	Lethal and sublethal effects of impaired ability to breed and shelter due to changes in surface (vegetative or soil) structure; habitat degradation.
Nutritional compromise	Effects of change in vegetation composition; affects growth rates in juveniles to female reproductive output and can result in death by starvation; habitat degradation.
Population fragmentation	Results from barriers to movement from urbanization, fences, roads and railroads, aqueducts, and energy development, and can limit the movement of animals, their ability to behaviorally improve their chance of survival. This lack of movement is accompanied by a proportional reduction in flow of genetic material and an increase in mortality reducing genetic diversity and the ability to adapt to changing conditions.
Predation	Mortality due to getting eaten at any life stage, including eggs, hatchlings, juveniles, and adults.
Small population and stochastic effects	Small populations have a higher likelihood of extirpation as a result of any mortality (or recruitment) effect
Toxicosis	Mortality or sublethal effects due to effects of a poison or toxin.

Population Effects (4)

RATE NAME	DESCRIPTION
Change in Immigration/Emigration	Immigration - Movement of individuals into the local area and perhaps into an existing population, from a neighboring region and neighboring population; Emigration - Movement of individuals from the local population, through the landscape to a neighboring region and perhaps into a neighboring population.
Change in Mortality (Adult)	Adult, reproductive individuals lost from the population due to mortality
Change in Mortality (Juvenile)	Juvenile, pre-reproductive individuals lost from the population due to mortality
Change in Reproductive Output	Individuals added to the population due to reproduction (in this case, reproductive output, rather than survival to age class 1)

Recovery Action Types (27)

Recovery Actions	Description
Connect habitat (culverts/underpasses)	Incorporate culverts and underpasses into road-fencing projects as well as any state or federal road or highway improvement/expansion to minimize fragmenting effects of roads.
Control dogs	Actions may include developing free-ranging dog management plans and/or live-trapping free-ranging dogs in specific problem areas.
Decrease predator access to human subsidies	Limit predator access to anthropogenic resources (e.g., food and water obtained at landfills, commercial trash, sewer and evaporation ponds, confined livestock feeding operations such as dairies and stables, and from road kills; also includes anthropogenic nesting and perching sites)
Designate and close roads (travel management plan)	Designate existing roads as open, closed, or limited; avoid establishment of new roads within tortoise habitat; close non-essential or redundant routes within tortoise conservation areas.
Environmental Education	Facilitates awareness of the conservation status of the desert tortoise and provides information through interpretive signs at various waystations or parks. Activities include:
	Tortoise trunks: Provide education kits to local grade school teachers.
	Training: The Desert Tortoise Conservation is expected to play an integral role in range-wide training and education opportunities in the near future.
	Brochures: Develop brochures for distribution by management agencies to recreationists or others; identify the importance of desert stewardship desert tortoise and the need for regulated access and use of habitat and encourage reporting of problem illegal activities.
	Utilize kiosks: Utilize NPS and BLM interpretive kiosks or visitor centers to disseminate information about the desert tortoise and the need for regulated access and use of habitat and encourage reporting of problem illegal activities.
	PSAs: Utilize public service announcements, news releases, informational videos, brochures and newsletters, websites, and tv; identify the importance of desert stewardship desert tortoise and the need for

	regulated access and use of habitat and encourage reporting of problem illegal activities.
	Volunteers: Provide volunteer opportunities.
	Permitting system: Consider developing a permit system for access to sensitive areas to educate desert recreationists.
Fire management planning and implementation	Identify and map priority areas; develop a fire plan for habitat protection.
Increase law enforcement	Activities include:
	Increase fines: Consider increasing fines to deter unauthorized OHV, vandalism, dumping/littering, etc.
	Cross-jurisdictional agreements: Establish agreements between offices of adjacent management authorities to enforce regulations across jurisdictional lines would also improve the effectiveness of law enforcement efforts.
	Non-LE rangers: Use "rangers" or other personnel as a physical presence in the field who would make contact with public land users, communicate with law enforcement officers, and conduct other activities, as necessary (e.g., minor restoration or trash removal).
	LE-rangers: Use existing officers to ensure law enforcement presence during peak recreational use (to deter unauthorized ORV; vandalism; dumping/littering)
Install and maintain human barriers (preserves)	Physically block boundaries around designated preserves at-risk to unauthorized human intrusion (e.g. Desert Tortoise Natural Area, Red Cliffs Desert Preserve)
Install and maintain human barriers (wildland-urban interface)	Physically block boundaries around the wildland-urban interface adjacent to tortoise conservation areas
Install and maintain tortoise barrier fencing	Install tortoise-barrier fencing along highways and paved roads within or adjacent to tortoise conservation areas
Install and maintain tortoise barriers (open OHV areas)	Install tortoise-barrier fencing along highways and paved roads within or adjacent to tortoise conservation areas and/or other areas which should exclude tortoises
Land acquisition	Acquire private in-holdings to improve management capability of the surrounding area and/or connect functional habitat
Landfill management	Reduce or eliminate the use of authorized landfills by tortoise predators.
Manage disease in captive population (permitting)	New State and/or local regulations regarding keeping tortoises as pets may be necessary and existing regulations should be enforced. New regulations should restrict the number of desert tortoises a household can possess, restrict or ban contact with other tortoises species, require health assessments, and specify containment conditions to minimize the chances of escape.
Manage disease in wild population	Monitor uninfected populations that have recently become infected and remove all individuals exhibiting acute infections. In populations known to be uninfected, remove individual tortoises exhibiting clinical signs of acute infection for further testing; return to the point of capture if diagnostic tests confirm they are uninfected.

Minimize wild horse and burro impacts	Continue to exclude horses and burros from desert tortoise conservation areas by fencing and/or removal
Remove grazing (close allotments)	Remove livestock grazing from tortoise conservation areas.
Restore Habitat	Restore and revegetate degraded areas with native plants of high nutritive quality to desert tortoises, as well as shrubs needed for cover for smaller-scale applications
Restore habitat (garbage clean up)	Remove garbage from tortoise conservation areas.
Restore habitat (toxicants/unexploded ordinance)	Remove toxicants (mining sites, unauthorized dump sites) and unexploded ordinance.
Restore roads (e.g. vertical mulching-roads)	Obscure and restore closed segments and of roads/routes and illegal incursions within tortoise conservation areas that are visible from points along nearby open routes.
Restrict OHV events	OHV events should avoid existing tortoise conservation areas; limit the number of events per year, limit events to the winter season, and limit the number of participants per event.
Sign and fence protected areas	Physically block and mark boundaries of protected areas (particularly in the Upper Virgin River RU), mitigation lands, translocation areas, research sites, military lands, and parks, particularly when an area is vulnerable to vehicular or livestock intrusion.
Sign Designated Routes	Install and maintain signs for designated (closed and open) routes within tortoise conservation areas
Speed limits	Consideration should be given to posting speed limits on appropriate rural paved and all unpaved roads (25 MPH).
Targeted predator control	Control methods include targeted removal of known tortoise predators by shooting or trapping (live or lethal), as well as nest removal, directed at specific problem areas within tortoise conservation areas or where predation is affecting specific recovery-related research.
Withdraw mining	Withdraw or otherwise limit mining through mining plans of operations, within tortoise conservation areas or where indirect effects from adjacent areas would affect these areas.

APPENDIX B:
Demographic Modeling Report: Effects of threats on demography of Mojave desert tortoise

Effects of threats on demography of Mojave desert tortoise populations

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9 November 2012

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Summary

As part of efforts to foster recovery of the Mojave desert tortoise (*Gopherus agassizii*), the U.S. Fish and Wildlife Service's Desert Tortoise Recovery Office has been developing a Spatial Decision Support System (SDSS). The SDSS is designed to quantify threats to the desert tortoise in a spatially explicit manner to facilitate the process of prioritizing recovery actions. Although threats to populations of desert tortoises throughout their range in the United States have been catalogued, likely changes in demographic rates (i.e., survival, reproduction, and transition rates) in response to threats have not been established. These relationships, however, are necessary to determine which threats are likely to have severe consequences for persistence of tortoise populations over the long-term and are necessary to prioritize recovery actions to ameliorate those threats. Therefore, we developed a series of models to predict effects of several pervasive threats on rates of adult survival, juvenile survival, and reproductive output. In this document, we describe and document models that we developed to predict changes in demographic rates of desert tortoises in response to raven predation, mortality from vehicles on roads, and cattle grazing.

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MODEL 1
Quantifying mortality of juvenile tortoises due to raven predation

Predation of juvenile desert tortoises (*Gopherus agassizii*) by common ravens (*Corvus corax*) occurs primarily by breeding ravens in the vicinity of their nests and by non-breeding ravens in the vicinity of food resources provided by humans, known as anthropogenic subsidies (Kristan and Boarman 2003). Occasionally, juvenile tortoises are at risk of predation by both breeding and non-breeding ravens in areas where nests are located near subsidies and where non-breeding ravens make long-distance movements away from subsidies, but those instances are likely rare. Therefore, we separated the two primary sources of raven predation to model predation risk of tortoises by ravens.

Breeding ravens nest on natural structures, such as Joshua trees (*Yucca brevifolia*) and cliffs, and on artificial structures, such as electrical transmission towers. Because the density of nests is likely to be higher in utility corridors than in adjacent areas without abundant artificial nesting structures, we modeled predation risk separately in these areas. Consequently, we modeled predation risk for three distinct circumstances (Fig. 1):

1) predation by non-breeding ravens near anthropogenic subsidies,
2) predation by breeding ravens with nests in utility corridors, and
3) predation by breeding ravens with nests on natural structures (i.e., “background predation”).

Breeding ravens

Foraging behavior of breeding ravens

- Breeding ravens rely more heavily on natural prey than on anthropogenic food subsidies (Kristan and Boarman 2003).
- Breeding ravens spend most of their time foraging in close proximity to their nests (within a 400-m radius, Sherman 1993; mean foraging distance from nest = 570 m, Boarman and Heinrich 1999).

Predation rates near nests

- Predation risk is higher near successful raven nests (i.e., nests that produce at least one chick) than at unsuccessful nests (Kristan and Boarman 2003).
- Ravens prey upon tortoises whose shells have not completely ossified (approximate MCL <100 mm; Boarman and Heinrich 1999). Therefore, we assumed that approximately half of the juvenile stage class, which includes all tortoises with MCL <180 mm, are vulnerable to predation at any point in time.

Kristan and Boarman (2003) placed styrofoam models of juvenile tortoises in unobstructed locations throughout their study area in the western Mojave Desert for four days during the raven breeding season to estimate the probability of raven attack. Probability of attack approached 0.44-0.59 in close proximity to a successful nest that had relatively few other ravens in the vicinity. When we extrapolated these four-day predation probabilities over an entire raven breeding season, annual mortality rates for juvenile tortoises inhabiting areas near raven nests approached 1.0.

We calculated background mortality risk to juvenile tortoises across the landscape outside of utility corridors and mortality risk inside utility corridors after determining the density of successful raven nests in both of these areas.

Density of raven nests

Density of successful raven nests likely varies over space and time, although we lack the data needed to model this variation directly. Data from the North American Breeding Bird Survey (BBS), however, may prove informative if we make some simplifying assumptions. As part of the BBS, 24.5-mi routes have been surveyed for breeding birds throughout the range of the desert tortoise since the mid-1960s. Although every route was not surveyed every year, these data represent the most extensive information available on abundance of breeding birds over large spatial and temporal scales. We assumed that counts of ravens observed on these routes provided a reasonable index to abundance of ravens and successful raven nests, and used these counts to adjust existing estimates of nest density from other locations and time periods.

To evaluate these data, we overlaid BBS routes with desert tortoise recovery units in ArcGIS, and identified those routes where ≥1/3 of the survey points fell within a recovery unit. For each route, we calculated the mean number of ravens observed across all years the route was surveyed. We identified two areas of high raven abundance: in the extreme Western Mojave recovery unit and in the northern portion of the Northeastern recovery unit (Fig. 2). For the purposes of describing spatial variation in raven abundance, we divided the Western Mojave recovery unit into two regions, a western portion with higher raven abundance (WWM) and an eastern portion (EWM) with lower raven abundance. We then calculated the mean number of ravens counted across all routes in each region, after first dividing the Western Mojave recovery unit into two regions (WWM and EWM) and combining the Upper Virgin River and Northeastern Mojave recovery units into one region (UVRNE), with all routes in each region weighted equally regardless of when and how frequently a route was surveyed (Table 1). Routes that spanned more than one region were included in mean counts for both regions.

USGS has provided regional trend analyses for many species, including the common raven. For the Mojave and Colorado Deserts, they estimate that raven numbers have increased 3.1% annually between 1966 and 2010 (http://www.mbr-pwrc.usgs.gov/cgi-bin/atlasa10.pl?04860&1&10)

Background predation

Density of raven nests on natural structures

We identified two sources of data for estimating density of successful raven nests on natural structures. The first was a study by Knight and Kawashima (1993), where ravens, red-tailed hawks, and their nests were identified on linear transects surveyed by helicopter that were ≥3.2 km from highways or utility corridors in San Bernardino County, California. Sightings of raven nests on these transects were rare, with approximately one nest observed for every 1000 km surveyed (density = 0.00125 nests/km^2, assuming transects were 800 meters wide), although it seems likely that some nests went undetected during surveys. Based on other studies where aerial surveys were used to locate raven or raptor nests (Grier et al. 1981, Bowman and Schempf 1999, Booms et al. 2010), we made the conservative assumption that detection probability averaged 0.50. Because transects were surveyed late in the raven nesting season, we also assumed that all nests detected were successful. Based on these adjustments, we estimated there were 0.0025 raven nests/km^2 in the study area in 1989. Assuming a 3.1% annual increase in successful raven nests (see *Density of raven nests* section above), we estimated density of nests across the study area in 2012 to be 0.005 nests/km^2.

Kristan and Boarman (2007) studied the nesting biology of ravens in the western Mojave Desert near Edwards Air Force Base. Between 1996 and 2000, raven nests were surveyed and monitored across parts of the Air Force Base and in areas near the towns of Mojave and Rosamond. Over the 5-year study period, they mapped locations of 351 raven nests in a 600-km^2 area. Although they reported the study area as 770 km^2 in an earlier study (Kristan and Boarman 2003), we estimated the effective study area to be 600 km^2 after subtracting the approximate area of a dry lake bed, which is not considered habitat for ravens or desert tortoises.

To estimate density of successful raven nests based on data reported by Kristan and Boarman (2007) and to use this value to estimate background rates of predation, we used only those nests that were located in Joshua trees (n = 196), other trees (n = 46), and cliffs (n = 4). Only a subset of known nests were occupied in a given year, and we used annual counts of known and occupied nests provided in Table 1 of Kristan and Boarman (2007) to calculate the mean probability of occupancy. We assumed that in the beginning of the study they were more likely to find occupied nests than unoccupied nests; therefore, we excluded the first two years of data, calculated the probability of occupancy for each of the last three years, and averaged these values (0.65). Probability of producing at least one chick at an occupied nest in each survey year was also reported, and we used the mean of these values (0.33) to represent the probability of nest success, given occupancy. We then calculated the density of successful nests in natural structures at the time of the study as:

$$D_{successful\ nests} = D_{known\ nests} \times Pr(occupancy) \times Pr(success|occupancy),$$

$$D_{successful\ nests} = \left(\frac{246\ nests}{600\ km^2}\right) \times 0.65 \times 0.33,$$

$$D_{successful\ nests} = 0.088\ nests/km^2\ .$$

Finally, we assumed that abundance of successful raven nests increased 3.1% annually since the time of the study, resulting in a projected density of successful nests in 2012 of 0.127 nests/km^2.

The estimate of nest density based on data from Kristan and Boarman (2007; 0.127 nests/km^2) was more than 25 times higher than the estimate based on Knight and Kawashima (1993; 0.005 nests/km^2), even after adjusting for increases in density over time. Based on the regional BBS data, we might expect that estimates from the Western Mojave, where Kristan and Boarman worked, would be approximately four times higher than estimates from the Colorado Desert (CD), Eastern Mojave (EM), and EWM regions, where Knight and Kawashima worked. This discrepancy could be explained if the Kristan and Boarman (2007) study occurred in a location with extraordinarily high raven abundance, a situation that is supported by a route-specific analysis of the BBS data. The mean raven count for the route nearest the Kristan and Boarman (2007) study area (Willow Springs; mean = 45.9) was 38% larger than the second-highest count (California City route; mean = 33.3). Given that nest densities based on data from Kristan and Boarman (2007) are unlikely to reflect densities in other parts of the region, we based all of our estimates of nest density on data from Knight and Kawashima (1993) and adjusted them for each region based on relative abundance from BBS data (Table 1).

Mean counts of ravens on BBS routes, and therefore abundance of raven nests, were similar in the CD, EM, and EWM regions (Table 1). Counts were approximately 2.5 and 4 times higher in the UVRNE and WWM regions, respectively. We used these relative weights to estimate density of successful nests in each of the regions (Table 2).

Average mortality due to breeding ravens with nests in natural structures

We used the inverse of our estimates of the density of successful nests in each region to represent the average size of an area containing one successful nest (Table 2). We then assumed that (1) the area where juvenile tortoises are at risk of predation is defined by a circle with 500-m radius (0.79 km^2) centered on a successful raven nest (see *Foraging behavior of breeding ravens* section above), (2) annual predation risk for the entire juvenile stage class is equal to 0.5 and is constant across this area, and (3) raven-related mortality is equal to zero >500 meters from a successful nest (Fig. 3). Finally, we calculated the aerially weighted average of annual predation risk from breeding ravens nesting in natural structures far from anthropogenic subsidies (i.e., background predation) as:

$$Average\ annual\ mortality = \frac{(0.5\ \times 0.79\ km^2) + \left(0\ \times\ (x\ km^2\ - 0.79\ km^2\ )\right)}{x\ km^2},$$

where x represents the area containing one successful raven nest in each region. These calculations resulted in background mortality rates of 0.005 and 0.008 in the UVRNE and WWM regions, respectively, and 0.002 in all remaining regions (Table 2).

Predation by breeding ravens nesting in utility corridors

Density of raven nests in utility corridors

Along with transects in control areas, Knight and Kawashima (1993) surveyed utility corridors for raven nests, and we used these data to estimate density of nests in these corridors. Raven nests were more common on transects along utility corridors than along control transects, with approximately 4.2 nests observed for every 100 km surveyed along utility corridors (density = 0.042 nests/km^2). Similar to methods used to estimate density of nests in natural structures, we assumed that detection probability on surveys was 0.5, all nests observed were successful, and nest density increased 3.1% annually between 1989, when the surveys were completed, and 2012. Given these assumptions, predicted density of successful nests in utility corridors throughout the Knight and Kawashima (1993) study area in 2012 is 0.170 nests/km^2. If we used the BBS regional count data to adjust this estimate for other regions as we did for background mortality, then current estimates of nest density in UVRNE and WWR are 0.424 and 0.678, respectively (Table 3).

Although a number of studies have used point counts or driving transects along utility corridors or roads to assess abundance of ravens along linear features (Boarman and Coe 2002, McIntyre et al. 2007), it is difficult to extrapolate nest density from these data given that many surveys were completed outside of the breeding season. Steenhof et al. (1993) surveyed for raven and raptor nests for nine years along a newly-installed 596-km transmission line in Idaho. We expect that ravens have more resources in forested regions, like Idaho, than in many parts of the Mojave Desert, and as a result can support more breeding pairs of ravens. As predicted, estimates of nest density based on Steenhof et al. (1993; 0.308

successful nests/km^2) were higher than all regions except UVRNE and WWR, suggesting that estimates based on data from Knight and Kawashima (1993) are reasonable.

Average mortality due to breeding ravens with nests in utility corridors

Using the same approach we used to determine the level of background predation, we calculated the average area containing one successful nest, then calculated an aerially weighted average of mortality rates (Fig. 4). Based on these calculations, we expect annual mortality in 1-km wide utility corridors to be 0.167 and 0.268 in the UVRNE and WWM regions, respectively, and 0.067 in all other regions (Table 3).

Estimating the risk of predation of juvenile tortoises by non-breeding ravens

Spatial variation in predation rates

- Predation risk is highest near anthropogenic subsidies that attract large numbers of non-breeding ravens (Kristan and Boarman 2003).
- Not all subsidies attract large numbers of ravens. Raven abundance, and therefore predation risk, varies with type of subsidy, abundance of the human population near the subsidy, season, and time of day (Boarman et al. 2006).
- Probability of a raven attack on a juvenile tortoise approaches 1.0 in close proximity to a subsidy that is associated with large numbers of non-breeding ravens (Kristan and Boarman 2003).

Mortality at anthropogenic subsidies (distance to subsidy = 0)

Because we do not have locations of different types of subsidies and large numbers of ravens do not aggregate around every subsidy, we assumed that average juvenile mortality at a subsidy would be <1.0 and reduced estimated mortality rates by 20%, to 0.80. Similar to the methods used to approximate mortality rates due to breeding ravens, we divided mortality estimates due to non-breeding ravens in half because only a subset of individuals in the juvenile stage class are vulnerable to predation by ravens. These calculations resulted in an annual mortality estimate of 0.40 for tortoises with MCL <180 mm due to predation by non-breeding ravens at an anthropogenic subsidy.

Variation in mortality rates associated with distance to subsidies

Near successful nests, we assumed that juvenile tortoises are only vulnerable to predation <500 meters from the nest. Near anthropogenic subsidies, however, we expect that tortoises may be at risk of predation >500 meters from the subsidy because of the large number of non-breeding ravens present. Because ravens are central-place foragers (Sherman 1993), they are likely to spend most of their time foraging close to the subsidy, even though birds may travel longer distances from the subsidy to roosts or water sources (Boarman et al. 1995). For the model, we assumed that tortoises ≤500 meters from a subsidy are at the highest risk (annual mortality rate = 0.4), and risk to tortoises outside this 500-m buffer is likely to decrease exponentially with distance from the subsidy. Assuming that non-breeding ravens spend most of their time <4 km from a subsidy (Boarman et al. 1995), we expected that predation risk will reach background levels in areas ≥4 km from a subsidy (Fig. 5). It follows that annual mortality x meters from a subsidy in each region, $f(x)_{region}$, is given by:

$$f(x)_{WWM} = \begin{cases} 0.4, & if\ x < 500 \\ -0.004206 + 0.666423\ \times e^{(-0.001 \times x)}, & if\ 500\ \leq x < 4000 \\ 0.008, & if\ x \geq 4000 \end{cases}$$

$$f(x)_{UVRNE} = \begin{cases} 0.4, & if\ x < 500 \\ -0.007299 + 0.671523\ \times e^{(-0.001 \times x)}, & if\ 500\ \leq x < 4000 \\ 0.005, & if\ x \geq 4000 \end{cases}$$

$$f(x)_{CD,EM,EWM} = \begin{cases} 0.4, & if\ x < 500 \\ -0.010393 + 0.676623\ \times e^{(-0.001 \times x)}, & if\ 500\ \leq x < 4000 \\ 0.002, & if\ x \geq 4000 \end{cases}$$

Uncertainty in the model

There are two primary sources of uncertainty in our model of raven predation: model structure and parameter estimates. As stated above, we simplified model structure by dividing predation into that due to breeding ravens near nests and non-breeding ravens near anthropogenic subsidies. Predation of juvenile tortoises by breeding ravens with nests in close proximity to an anthropogenic subsidy is not explicitly accounted for in our model because modeling predation rates in these areas is difficult given the complex relationships between predation rates due to breeding ravens and abundance and proximity of non-breeding ravens (Kristan and Boarman 2003). Excluding predation at nests near subsidies is unlikely to change mean mortality rates considerably, however, given the relatively small foraging area of breeding ravens, the already elevated rates of predation near subsidies, and the reduced foraging efficiency of breeding ravens near large aggregations of non-breeding ravens because of time spent defending the nest and young (Kristan and Boarman 2003).

Where possible, parameter estimates were based on data available in the literature. Rates of predation by non-breeding ravens are somewhat uncertain given that predation rates are best determined by localized raven abundance, which varies with season, time of day, human abundance, and type of subsidy. As a result, not all subsidies pose equal risks to juvenile tortoises. Without spatial and temporal data describing local raven abundance, or fine-scale maps with locations and types of subsidies throughout the range of the desert tortoise, it is difficult to predict with certainty what areas pose the greatest risk to juvenile tortoises.

MODEL 2
Quantifying mortality of adult tortoises from motor vehicles on roads

Mortality of reptiles on roads has been well documented in southwestern deserts (Rosen and Lowe 1994, Sazaki et al. 1995), but converting these data to mortality rates is challenging because standardized carcass surveys are rare, carcasses often go undetected even during standardized surveys, and determining time-since-death, particularly for tortoises, is difficult. Most attempts to quantify the effects of roads on desert tortoises have not estimated mortality directly, but have focused on measuring decreases in abundance and sign of tortoises as a function of distance from the road (Berry 1986, von Seckendorff Hoff and Marlow 2002, Boarman and Sazaki 2006, Hughson and Darby 2011). Although useful to demonstrate the geographic extent of road effects, data from these studies cannot be used to estimate rates of mortality without having precise estimates of tortoise densities through time, rates of mortality from non-road-related sources, and associated rates of traffic flow.

To the best of our knowledge, standardized surveys for desert tortoise carcass have only been completed in one area of the western Mojave Desert (Sazaki et al. 1995, Boarman and Sazaki 1996). Because data from these studies were limited spatially and temporally, we did not use them to estimate annual mortality rates. We did, however, use these data to inform simulations we developed to verify the accuracy of our model, which we describe in the **Model verification** section.

Gibbs and Shriver (2002) developed a model to estimate effects of road mortality on persistence of terrestrial and aquatic turtles that was based heavily on earlier work for amphibians (Hels and Buchwald 2001). In the Gibbs and Shriver (2002) model, annual rates of road mortality varied with the number of road crossings a tortoise or turtle was expected to make during one year. The number of expected road crossings was estimated by overlaying simulated movements for different groups of chelonians on maps with varying road densities. For aquatic turtles, movements were characterized easily with linear forays between nesting sites and the edge of a water body. For terrestrial tortoises, however, movements were more complex, and characterized by many short-distance movements and occasional longer-distance movements in random directions. We doubted that these simulated movements represented those of a typical Mojave desert tortoise, which show considerable levels of site fidelity within and among seasons (Holt and Rautenstrauch 1996, Freilich et al. 2000, Harless et al. 2009). Further, their model was based on estimating annual mortality rates as a function of road density measured at a regional scale. We were charged with modeling annual mortality with a high-degree of spatial resolution, where road densities had the potential to be exceedingly low or zero across much of the target areas. For these reasons, we decided to create a model that was based on the probability that a tortoise was on a road at any given point in time during the active season rather than the cumulative number of annual road crossings. Despite these differences, the same basic structure underlies both our model and the Gibb and Shriver (2002) model, wherein annual mortality is a function of the probability a tortoise crosses a road and the conditional probability that it is struck by a vehicle while on the road. Specifically:

$$Annual\ mortality = Pr(tortoise\ on\ road) \times Pr(tortoise\ killed | tortoise\ on\ road).$$

Although tortoises in all stage classes are at risk of mortality on roads, we only modeled mortality rates for adults (midline carapace length ≥180 mm). Generally, mortality rates of juveniles are more difficult to estimate than those of adults because their carcasses are more difficult to detect and do not persist as long as adult carcasses. Further, unlike adult tortoises, little is known about movements, home-range sizes, and site fidelity of juvenile tortoises, making generalizations about their movement patterns difficult. For this reason, we did not model annual rates of road-related mortality for juveniles.

Finally, there are many indirect effects of roads on desert tortoise populations that act on local, regional, and landscape-level scales. Roads increase accessibility of humans to remote areas, and may increase the likelihood that wild tortoises are collected illegally or that captive tortoises are released, potentially introducing disease (Tomlinson and Hardenbrook 1993, Johnson et al. 2006, Martel et al.

2009, Grandmaison and Frary 2012). Roads also serve as corridors for the introduction of nonnative plants and toxicants, and may alter the permeability of soils along road edges (Gelbard and Belnap 2003, Brooks and Lair 2005, Chaffee and Berry 2006). Finally, the cumulative effects of roads may decrease landscape connectivity among populations of desert tortoises (Brooks and Lair 2005). Although our model solely characterizes direct mortality of adult tortoises from vehicles on roads, we acknowledge that the cumulative indirect effects are likely to have consequences for long-term persistence of desert tortoises in the Mojave Desert.

Probability that a tortoise is on a road

The probability that an adult tortoise is on a road at any given point in time is a function of the size of the area a tortoise uses typically (i.e., home range) and the location of the road in relation to that area. To create a probabilistic model of road-related mortality, we made some generalizations regarding activity and movements of tortoises. First, we assumed that a tortoise has a “core area” where they spend the majority of their time. We know from telemetry studies, however, that tortoises occasionally make longer-distance movements or “forays” outside of this core area (Sazaki et al. 1995, Boarman et al. 1996, Freilich et al. 2000). A tortoise could cross a road while making short-distance movements within the core area or while making a longer-distance movement to gain access to mates or foraging opportunities; we incorporated both of these possibilities in our model.

Many estimates of home-range size have been published for desert tortoises, including those that characterized area with methods based on minimum convex polygons (MCP) and kernel estimators. A MCP is created by drawing a polygon around all telemetry locations such that no internal angle is >180° (Hanye 1949, Powell 2000). Although MCP methods are used commonly, they often overestimate home-range size because they include areas that are never used by the animal (Powell 2000). Kernel methods use telemetry locations to create a probability surface for animal activity, identifying those areas that are used most frequently. Estimates of home-range size based these methods are often calculated as the size of the smallest area where probability of use is 0.95 (Powell 2000).

Although shape and intensity of use within home ranges are likely to vary seasonally and regionally with factors including topography, soil, and distribution of conspecifics and resources, we assumed the core area was circular. We used home-range estimates based on 95% kernel densities to approximate the core area and assumed this represents the area where a tortoise would be expected to spend 95% of its time. We then assumed that tortoises will spend the remaining 5% of their time outside of this core area, as part of longer-distance movements away from their activity center. We used MCP estimates that included long-distance movements and forays to define the boundary of this area, hereafter the “peripheral home range” (Fig. 6). Although many MCP and 95% kernel estimates were available from studies of the Mojave desert tortoise, we used estimates from a recent study that used standardized methods, had large sample sizes (35 adult tortoises that were located >6800 times over two years), and included all long-distance movements in home range estimates (Harless et al. 2010). We averaged estimates for males and females because we needed a single model of annual road-related mortality for the adult population. This resulted in a core area of 23 ha, with a radius of 270 m, and total area (core + peripheral home range area) of 35 ha, with a radius of 334 meters (Fig. 6).

Although unlikely for any individual, we assumed that tortoises use these areas uniformly, which enabled us to estimate the probability that a tortoise is on a road by calculating the proportion of core and peripheral home-range areas that are covered by road. The proportion of the area covered by road is a function of the perpendicular distance between the road and the activity center of the tortoise; the closer the activity center is to the road, the greater the length of road that intersects the core and peripheral home-range areas. To calculate the proportional area of the road, we also needed an estimate of road width. In the model, we substituted vehicle width for road width because the tortoise is only at risk when in the path of an oncoming vehicle, assuming no behavioral response of the driver to the tortoise. We calculated a weighted average of vehicle width (2.0 m; VW) for light- and heavy-duty vehicles after obtaining the width and annual miles driven for each vehicle type from the U.S. Department of Transportation.

The probability that a tortoise is in a road that intersects the peripheral home-range area but not the core area, $Pr(tort\ in\ road)_{PHR}$, is given by:

$$Pr(tort\ in\ road)_{PHR} = \frac{road\ length_{PHR}\ \times VW}{Area_{PHR}} \times\ Pr(tort\ in\ PHR),$$

$$Pr(tort\ in\ road)_{PHR} = \frac{road\ length_{PHR}\ \times 2.0}{(35-23)ha} \times 0.05,$$

$$Pr(tort\ in\ road)_{PHR} = \frac{road\ length_{PHR}\ \times 2.0}{120{,}000\ m^2} \times 0.05,$$

$$Pr(tort\ in\ road)_{PHR} =\ 0.00000083\ \times\ road\ length_{PHR},$$

where $road\ length_{PHR}$, or length of the road that intersects the peripheral home-range area in meters, is a function of the distance between the road and the activity center of the tortoise, D:

$$road\ length_{PHR} = 2\ \times\ \sqrt{{radius_{PHR}}^2 -\ D^2}.$$

Similarly, the probability that a tortoise is in a road that intersects the core area, $Pr(tortoise\ in\ road)_{CA}$, is given by:

$$Pr(tort\ in\ road)_{CA} = \left(\frac{road\ length_{CA}\ \times VW}{Area_{CA}} \times Pr(tort\ in\ CA)\right) + \left(\frac{road\ length_{PHR}\ \times VW}{Area_{PHR}} \times Pr(tort\ in\ PHR)\right),$$

$$Pr(tort\ in\ road)_{CA} = \left(\frac{road\ length_{CA}\ \times 2.0}{230{,}000\ m^2} \times 0.95\right) + \left(\frac{road\ length_{PHR}\ \times 2.0}{120{,}000\ m^2} \times 0.05\right),$$

where $road\ length_{CA}$ and $road\ length_{PHR}$, represent the length of the road that intersects the core area and intersects the peripheral home-range area outside of the core area in meters, respectively:

$$road\ length_{CA} = 2\ \times\ \sqrt{{radius_{CA}}^2 -\ D^2}, \text{ and}$$

$$road\ length_{PHR} = \left(2\ \times\ \sqrt{{radius_{PHR}}^2 -\ D^2}\right) - \left(2\ \times\ \sqrt{{radius_{CA}}^2 -\ D^2}\right).$$

Clearly, the probability that a tortoise is on a road is higher for those roads that intersect the core area, where a tortoise spends most of its time, and is considerably lower for those roads that only intersect the peripheral home-range area (Fig. 7). The probabilities specified above apply only to single-lane roads. We will account for multiple lanes when we assemble all aspects of the model in the **Annual mortality risk** section. Additionally, as part of assuming that a tortoise uses areas uniformly, we assumed that tortoises had no behavioral responses to the road (i.e., avoidance or preference). Finally, we assumed that the generalizations made regarding core and peripheral home-range areas applied to the entire adult class. Specifically, we assumed that movements and activities of young adults were similar to those of older adults, with established home ranges and activity areas.

Probability that a tortoise on a road is struck and killed by a motor vehicle

The probability that a vehicle will strike a tortoise on a road is a function of traffic volume (number of vehicles/minute/lane) and the time required for a tortoise to cross the vehicle path, assuming that (1) a tortoise anywhere in the vehicle path, including between the tires, will be killed by an oncoming vehicle, (2) tortoises cross roads perpendicularly at a constant rate of speed, and (3) the driver does not respond to a tortoise in the road.

Estimates of traffic volume, often reported as the mean number of vehicles per day for both directions of travel, can be obtained for interstate and state highways from state departments of transportation (e.g., Caltrans), and estimates for smaller roads obtained from individual counties. We reduced daily estimates of traffic volume by 20% because traffic between 6 AM and 6 PM accounts for 80% of total daily volume (Festin 1996) and tortoises are only active and at risk during daylight hours.

The time required for a tortoise to cross a vehicle path perpendicularly is likely to vary among individuals and with environmental conditions. To reduce model complexity, we used a single estimate of tortoise locomotive speed (5 meters/minute) that was based on several studies (Pope 1939, Woodbury and Hard 1948, Leviton 1970, Burge 1977, Coombs 1977b) and was similar to estimates from locomotive studies of box turtles (*Terrepene* spp.; Muegel and Claussen 1994, Wren et al. 1998). Based on this estimate, a tortoise is expected to cross a 2-meter wide vehicle path in 24 seconds. If traffic volume were constant and ≥1 vehicle/24 seconds/lane, or 2.5 vehicles/minute/lane, then any tortoise that attempted to cross the road would be struck and killed. Below this threshold, however, we assumed that the conditional probability of a tortoise being struck would vary linearly as a function of traffic volume (Fig. 8), where:

$$Pr(tortoise\ killed|tortoise\ on\ road) = 0.4\ \times traffic\ volume\ ((no.vehicles/min)/lane).$$

It follows then that the probability that a tortoise is killed by a vehicle, conditional on tortoise presence on the road, is solely a function of traffic volume, and therefore can be calculated for different types of roads on a regional or seasonal basis with adequate information about variation in traffic volumes.

Annual mortality risk

We calculated the probability of a tortoise crossing a single vehicle path and the conditional probability that it is struck on a per-lane basis. Because most roads have multiple lanes, however, the probability that a tortoise will be killed on a road that intersects its core or peripheral home-range areas increases proportionally with the number of travel lanes. We expected an additive relationship for mortality risk from multiple lanes because for a two-lane road, for example, a tortoise could be struck while crossing the first lane or the second lane, but could not be struck crossing both. Specifically:

$$\begin{aligned} Annual\ mortality = {} & Pr(tortoise\ in\ lane\ A) \times Pr(tortoise\ killed | tortoise\ in\ lane\ A) + \\ & Pr(tortoise\ in\ lane\ B) \times Pr(tortoise\ killed | tortoise\ in\ lane\ B). \end{aligned}$$

Assuming $Pr(tortoise\ in\ lane\ A)$ is approximately equal to $Pr(tortoise\ in\ lane\ B)$, given that the perpendicular distances from the activity center to each lane differ only slightly and assuming that traffic volume is the same for each lane, it follows that:

$$Annual\ mortality = no.\ lanes \times Pr(tortoise\ in\ lane) \times Pr(tortoise\ killed | tortoise\ in\ lane).$$

Thus, mortality rates depend on the proximity of a tortoise's activity center to a road and characteristics of that road. Generally, annual mortality for a tortoise whose activity center is x meters from a road with low traffic volume (TV <2.5 vehicles/min/lane) and L lanes, $f(x)_{LV}$ (assuming average vehicle width is 2 meters and average core and total home-range sizes are 23 ha and 35 ha, respectively) is given by:

$$f(x)_{LV} = \begin{cases} 0.4 \times L \times TV \times \left[\dfrac{3.8\sqrt{270^2 - x^2}}{230{,}000} + \dfrac{0.2\left(\sqrt{334^2 - x^2} - \sqrt{270^2 - x^2}\right)}{120{,}000} \right], & if\ x \le 270 \\ 0.08 \times L \times TV \times \dfrac{\sqrt{334^2 - x^2}}{120{,}000}, & if\ 270 < x \le 334 \end{cases}$$

Similarly, annual mortality for a tortoise near a road with high traffic volume (TV ≥2.5 vehicles/min/lane), $f(x)_{HV}$, is given by:

$$f(x)_{HV} = \begin{cases} L \times \left[\dfrac{3.8\sqrt{270^2 - x^2}}{230{,}000} + \dfrac{0.2\left(\sqrt{334^2 - x^2} - \sqrt{270^2 - x^2}\right)}{120{,}000} \right], & if\ x \le 270 \\ 0.2 \times L \times \dfrac{\sqrt{334^2 - x^2}}{120{,}000}, & if\ 270 < x \le 334 \end{cases}$$

We calculated annual mortality rates for three roads that represented the range of conditions throughout the Mojave Desert (four-lane, high traffic volume; two-lane, moderate traffic volume; two-lane, low traffic volume) to demonstrate variation in annual mortality that might be expected for tortoises whose activity centers are <334 meters from a road (Fig. 9).

Model verification

We simulated data to evaluate whether our probabilistic model produced estimates of annual mortality that reflected empirical data from carcass surveys in the western Mojave Desert (Sazaki et al. 1995). In 1991, surveys for carcasses of desert tortoises were completed along both sides of an unfenced, 24-km section of California State Highway 395, south of Kramer Junction. Once found, carcasses were removed, regardless of condition or time-since-death. When the section of highway was resurveyed in 1992 and 1993, 13 and 5 carcasses were found, respectively (0.54 and 0.21 carcasses/km/year, respectively). Size classes of carcasses were not reported, but it seems reasonable to assume that at least some of the tortoises that died had MCLs <180 mm. A concurrent radio-telemetry study in the same area documented many long-distance movements by juvenile and sub-adult tortoises (MCL <208 mm), potentially putting them at higher risk of road-related mortality (Sazaki et al. 1995).

To simulate data and contrast estimates from our model to those reported in Sazaki et al. (1995), we needed estimates of tortoise density and traffic volume along Hwy 395 in the early 1990s. In 1987, a long-term study plot <25 km from Hwy 395 (Kramer Hills) was surveyed for tortoises, and the density of adult tortoises was approximately 37/km^2 (Luke et al. 1991). Traffic volume was approximately 8500 vehicles/day, or 4.72 vehicles/minute/lane (Boarman and Sazaki 1996).

To simulate data, we calculated the number of tortoises at risk along both sides of a 1-km segment of highway given density estimates and the radius of a peripheral home-range area of 334 meters. For each simulation, we selected random distances between the activity center of each tortoise and the road, up to 334 meters. We then calculated the probability each tortoise was on the road, and the probability that it would be struck if on the road based given our assumed level of traffic volume. Finally, we determined whether each tortoise lived or died with a single Bernoulli trial using the unique probability of mortality based on the distance between its activity center and the road. For each of 10,000 simulations, we calculated the number of tortoises that died per km of road. We estimated that 26 adult tortoises were at risk along each 1-km segment of road, and average mortality was 0.15 adults/km/year.

Our estimate of adult annual mortality was slightly lower than those reported in Sazaki et al. (1995) if we assume that all carcasses they found were from individuals with MCL ≥180mm. If several of the carcasses found in 1992 and 1993 were from juveniles or sub-adults, then 0.54 and 0.21 carcasses/km/year are overestimates of adult annual mortality. They could be underestimates, however, if many carcasses were not detected by surveyors in 1992 or 1993. Without additional details, it may be impossible to determine the degree and direction of bias in the estimates from Sazaki et al. (1995). Regardless, the simulations suggest that our model produces estimates that are reasonable, and lends support to the structure and logic underlying the model.

Uncertainty in the model

There are two primary sources of uncertainty in the model we developed for road-related mortality of adult tortoises: model structure and parameter estimates. We made many assumptions that simplified model structure, including but not limited to (1) tortoises use core and peripheral home range areas uniformly, (2) activity patterns are consistent over the entire adult stage class, and (3) no behavioral responses by tortoises or drivers. We recognize that the assumptions we made about tortoise movements and activity patterns simplify a set of complex processes, but we assert that simplifications were needed to develop a model that could be applied to desert tortoise populations throughout their range despite the lack of empirical data.

As stated previously, we created a model that reflects annual mortality rates for adult tortoises with established home ranges, and probably does not capture mortality rates of young adults that are more likely to make long-distance movements (Sazaki et al. 1995). As such, annual mortality rates from our model likely underestimate mortality for the adult stage class as a whole. Finally, given the structure of our model, annual road mortality is effectively zero for tortoises with activity centers >334 meters from a road. Although we know that tortoises occasionally move >334 meters from activity centers, these types of movements are rare and could not be incorporated effectively into our model. Road effect surveys have documented that tortoise abundance and sign is often reduced ≥1 km or more from road edges (Berry 1986, von Seckendorff Hoff and Marlow 2002, Boarman and Sazaki 2006, Hughson and Darby 2011) and upon first glance our model may seem to contradict those findings. However, our model does not account for interannual movements. When tortoises near roads are killed, other tortoises may move into these newly-unoccupied areas, and consequently increase their risk of future road mortality. These processes may ultimately contribute to reduced numbers of tortoises >334 meters from roads over the long-term.

Quantifying demographic effects of livestock grazing on desert tortoises

Livestock grazing might affect demography of desert tortoise populations directly, by mechanisms such as trampling, and indirectly, by reducing the quantity and quality of habitat by reducing vegetation cover or the abundance and availability of burrows from soil compaction. Although habitat degradation from livestock grazing is likely to have the most severe and persistent affects (Berry 1978, Oldemeyer 1994), we focused on ways grazing might affect demography of tortoises.

We evaluated the potential effects of grazing by cattle, but not by sheep. Although we know that direct and indirect effects of sheep grazing can be substantial, we did not have information on the spatial extent and intensity of sheep grazing within the range of the desert tortoise, limiting our ability to model demographic effects on tortoise populations. In addition, we did not want to apply the model we developed for cattle grazing to sheep grazing, because effects of cattle and sheep grazing on tortoises are likely to differ considerably. Where it occurs in the Mojave Desert, cattle grazing tends to be a low-intensity, persistent threat, whereas sheep grazing is usually a high-intensity threat of considerably shorter duration (Nicholson and Humphreys 1981, Avery 1998).

Empirical data

Two plots, each 2.6 km^2, were established on the Beaver Dam Slope in northwestern Arizona in the 1970s to study the effects of cattle grazing on desert tortoise populations (Hohman and Ohmart 1980). Tortoises on the Beaver Dam Slope had been studied since the 1930s (Woodbury and Hardy 1948), with evidence that the population began to decline before the 1970s (Coombs 1977a, Luke et al. 1991). Cattle were grazed in this area without restriction up until 1934. By the early 1980s, however, a rotational grazing system was established, where reduced numbers of cattle were permitted to graze in April and May in two consecutive years, followed by a year where no grazing was permitted (Animal Unit Months [AUMs] reduced from >5900 to approximately 1000 by 1977; Duck and Snider 1987, Luke et al. 1991).

On one of the study plots, cattle and tortoises were allowed to move on and off of the plot freely; on the second plot, which was located <8 km from the first, cattle were excluded by fencing, but desert tortoises could move freely on and off the plot. Each plot was surveyed 6-7 times between 1977 and 2002, during which time tortoises were uniquely marked and recaptures were noted. We used these capture-recapture data for adult tortoises (midline carapace length ≥180 mm) in Cormack-Jolly-Seber models to assess whether annual survival of tortoises differed between plots.

Over the 25-year period, annual survival of adult tortoises was marginally lower at the ungrazed site (0.86, 95% CI = 0.64-0.95) than the grazed site (0.90, 95% CI = 0.88-0.92), although survival at both sites was somewhat lower than expected for this long-lived species. Survival of desert tortoises may not have differed between sites for at least three reasons. First, effects of intensive cattle grazing on soil and vegetation may persist for decades, particularly in areas like the Beaver Dam Slope that were grazed intensively for up to a century. Second, the ungrazed plot was located near the site where Woodbury and Hardy studied desert tortoises in the 1930s and 1940s, which lured collectors for the pet trade. Finally, anywhere from 70-114 captive tortoises were released into the Beaver Dam Slope population prior to 1977 (Coombs 1977a, Luke et al. 1991). Although the exact number of captives and release sites are uncertain, an introduction of this magnitude is likely to affect behavior and demography of the resident population of tortoises (Berry 1986). Clearly, any subsequent estimates of population-level attributes would be unlikely to represent values under normal conditions.

Because the results of our effort to model the effects of grazing on survival with empirical capture-recapture data were questionable, we created two probabilistic models to describe some of the potential demographic effects of cattle grazing on desert tortoises. The first model quantifies direct mortality of adult tortoises from trampling by domestic cattle and the second model quantifies effects of cattle grazing on reproductive output of desert tortoises.

MODEL 3A
Quantifying mortality of adult tortoises from trampling by domestic cattle

An experimental study demonstrated that cattle avoid stepping on grass tussocks, presumably to avoid uneven surfaces (Balph and Malecheck 1985). In addition, during hundreds of hours of observation, Avery and Neibergs (1997) never observed a cow stepping on a tortoise and only once observed a cow contacting a tortoise, by nudging the tortoise with its head and neck. Therefore, we assumed that the probability of a cow trampling and killing an adult tortoise outside of a burrow was so low as to be negligible, and as a result we did not consider it in our model. Juvenile tortoises may be at higher risk of trampling because they are smaller and less likely to be seen by cattle; this might explain the instance where a carcass of a juvenile tortoise was found with a hoof-shaped hole in its carapace (Berry 1978). Given that we were modeling mortality rates of adults, however, we assumed that trampling events were likely to be very rare.

Trampling of tortoise burrows

An adult tortoise is at risk of mortality if it is in a burrow that is trampled by a cow. Hypothetically, mortality can occur if the hoof punctures the roof of the burrow and crushes a tortoise directly or if trampling damages the burrow sufficiently to entrap a tortoise. Regardless of the mechanism, annual mortality risk to tortoises in burrows can be expressed as a function of three probabilities:

$$\begin{aligned} &Annual\ mortality \\ &\quad = Pr(cow\ tramples\ burrow) \times Pr(tortoise\ in\ burrow) \times \\ &\quad\ \ Pr(tortoise\ killed | tortoise\ in\ burrow). \end{aligned}$$

Probability that a cow tramples a burrow

Generally, we expected that the probability that a burrow is damaged by cattle will increase as local stocking rates increase. Although sample sizes were small, the best data available to inform this relationship were obtained as part of a study evaluating effects of cattle grazing on the nutritional ecology of desert tortoises in the eastern Mojave. During winter and spring 1993, more burrows were damaged outside of a cattle exclosure (i.e., where cattle were present at 1.56 head/km^2; 5 of 10 burrows damaged) than inside (1 of 8 damaged; Avery and Neibergs 1997). We assumed that burrow damage could occur for reasons other than trampling by cattle, such as from flooding, and the rates that Avery and Neibergs (1997) observed inside the grazing exclosure represented this background rate. We estimated burrow damage from trampling as the difference between the two rates:

$$Pr(cow\ tramples\ burrow) = Pr(burrow\ damaged | cattle\ present) - Pr(burrow\ damaged | cattle\ absent),$$

$$Pr(cow\ tramples\ burrow) = (5/10) - (1/8),$$

$$Pr(cow\ tramples\ burrow) = 0.375.$$

A second source of data came from a population of Sonoran desert tortoises in northwestern Arizona. In a report detailing survey efforts on a long-term monitoring plot, Woodman et al. (1998) attributed damage to tortoise burrows to recent cattle grazing. Although the report was somewhat unclear, approximately 17% of tortoise burrows were damaged in one year (31 of 187 burrows damaged). Because the number of cattle per square kilometer was not reported, we extrapolated stocking rates from information in the report and from an environmental statement issued by the Bureau of Land Management on grazing programs in Mohave County, Arizona (BLM 1978). We assumed that (1) the allotment consisted of three pastures that were grazed on a rotating schedule (BLM 1978), (2) the allotment was approximately 330 km^2 (Woodman et al. 1998), with each pasture equal in size (approximately 110 km^2), and (3) 55 cattle grazed the allotment in 1997 (Woodman et al. 1998), and consequently estimated stocking rates of approximately 0.5 head/km^2.

Using estimates from Avery and Neibergs (1997) and Woodman et al. (1998), and assuming zero probability of damage from cattle when stocking rates were zero, we derived a linear relationship between stocking rates and probability of burrow damage from cattle (Fig. 10):

$$Pr(cow\ tramples\ burrow) = 0.24306\ \times stocking\ rate\ (head/km^2).$$

We considered this model to provide reasonable estimates for the probability of damage for stocking rates ≤3.0 head/km^2, which, to the best of our knowledge, encompasses the range of typical stocking rates in the Mojave Desert over the past several decades (Tracy et al. 1995, Avery 1998, BLM 2006, 2007, *unpublished data*).

Probability that a burrow is occupied by a tortoise

Probability of a burrow being occupied by an adult tortoise is a function of the ratio of burrows to adult tortoises and the probability that a tortoise is below ground. Tortoises use a wide variety of shelters (i.e., soil burrows, rock dens, pallets) that vary with soil type, topography, season, and weather. Quality of shelters, particularly soil burrows, varies; consequently, most surveys for Mojave desert tortoises rate the condition of all tortoise burrows observed from “poor” at the low end of the scale to “excellent” or “active” at the high end. Considering only those burrows rated “excellent” or “active,” the estimated number of burrows per adult tortoise ranged from 2.7 and 3.2 at Western Mojave and Eastern Mojave sites, respectively (Bury and Luckenbach 2002; *unpublished data* from the Ivanpah Solar Electric Generating System site) to between 4 and 13 burrows per adult at Colorado Desert and southwestern Mojave Desert sites (Krzysik 2002 and citations therein). When burrows with lower ratings were included, the number of burrows per adult ranged between 8 and 20 at the same Colorado Desert and southwestern Mojave Desert sites (Krzysik 2002). Although the number of burrows per adult tortoise is sure to vary considerably across the range of the desert tortoise, estimates from these sites seem reasonable and reflect average conditions assessed as a part of other large-scale monitoring efforts (A. Karl, *personal communication*).

Instead of adopting a single ratio of burrows to tortoises, we assumed that the number of burrows per tortoise varies with season because tortoises tend to use the highest-quality burrows in winter, as those burrows likely provide optimal thermal conditions for brumation. During the remainder of the year, however, tortoises use a variety of available burrows, depending on thermoregulatory needs and social interactions. Using estimates from studies described above, we assumed that the ratio of burrows to adult tortoises averaged 5:1 between mid-October and the end of February and averaged 10:1 between March and mid-October. Although we acknowledge that ratios are likely to vary over the range of the desert tortoise, we made no attempt to model spatial variation in this relationship because the features governing variation are unclear and likely to occur at a prohibitively-small scale for range-wide implementation of the model.

The proportion of time a tortoise spends below ground varies seasonally. Although many studies have evaluated activity patterns, we used only data from radio-telemetry studies to inform this parameter because we expected that surveyors would be more likely to encounter tortoises without radios when they were above ground, overestimating rates of surface activity. After adjusting for drought conditions, which we assumed occur once every five years (Hereford et al. 2006), estimates of surface activity were remarkably consistent among studies (Duda and Krzysik 1998, cited in Krzysik 2002; Duda et al. 1999; Nussear and Tracy 2007). Based on data from these studies, we assumed that the proportion of tortoises below ground averages 0.60 in the spring (March-May), 0.75 in the summer/fall (June-15 October), and 1.00 in the winter (16 October-February).

We then assumed the following relationships:

$$Pr(tortoise\ in\ a\ burrow\ that\ is\ trampled)$$
$$= Pr(burrow\ is\ used\ by\ a\ tortoise) \times\ Pr(tortoise\ below\ ground),$$

and calculated the seasonal probability that a tortoise is in a burrow that is trampled:

$$Spring\text{: } (1/no.of\ burrows\ per\ tortoise) \times Pr(tortoise\ below\ ground) = \left(\frac{1}{10}\right) \times 0.6\ = 0.06,$$

$$Summer/Fall\text{: } \left(\frac{1}{10}\right) \times 0.75 = 0.075,$$

$$Winter\text{: } \left(\frac{1}{5}\right) \times 1.00 = 0.20.$$

Finally, because we need estimates of annual mortality rates for the model, we calculated a weighted average of the seasonal values to obtain the mean probability a tortoise is in a trampled burrow across an entire year (0.12).

Probability of mortality for a tortoise in a damaged burrow

The degree of damage cattle can inflict on a burrow can vary, from a hoof penetrating the top of the burrow to collapsing the tunnel or entire burrow. Degree of damage is likely to be affected by factors such as soil composition and moisture content and the number, distribution, and activity of cattle in the area. Obviously, risk to a tortoise in a trampled burrow is likely to vary with the degree of damage. We thought it unlikely that a tortoise would be killed by a cow stepping through the top of a burrow given that the tortoise could be anywhere in the burrow tunnel and the potential force of hoof impact is likely to lessen after penetrating a thick soil layer. Therefore, we assumed that a tortoise is at risk of mortality only if cattle damage the burrow severely, resulting in at least partial collapse of the tunnel.

Although there are several anecdotal accounts of tortoises becoming trapped in collapsed burrows (Nicholson and Humphreys 1981, Nussear 2004, Lovich et al. 2011), most evidence suggests that these events are rare, especially when considering only those instances where cattle are responsible for burrow collapse. Cattle were implicated in only one of these instances (Nussear 2004), with sheep (Nicholson and Humphreys 1981) and flooding (Lovich et al. 2011) responsible for burrow collapse in the other two. In an experimental study evaluating the effects of burrow collapse on gopher tortoises (*Gopherus polyphemus*), 41 of 42 tortoises were able to extricate themselves from burrows collapsed by heavy-duty vehicles (Beauman 2008). Although gopher tortoises typically construct deeper burrows than desert tortoises (Hansen 1963, Luckenbach 1982), this suggests that in most cases, desert tortoises likely would be able to extricate themselves from a collapsed soil burrow. Further, there was no evidence of injury or harm to tortoises at the site in northwestern Arizona where burrow damage from cattle was extensive (Woodman et al. 1998).

Of burrows trampled by cattle at the Arizona site, approximately 75% had a single hoof-shaped hole in the top of the burrow and 25% had more extensive damage (Woodman et al. 1998). Based on the assumptions detailed above, we assumed mortality risk for tortoises in the 75% of trampled burrows with a single hole in the top was zero and was somewhat greater than zero for tortoises in the 25% of burrows with severe damage. Probability of mortality for a tortoise in a burrow with severe damage is likely to be low, based on the aforementioned studies. As a result, we established the probability of mortality as 0.20 for adult tortoises in burrows collapsed by cattle, a conservative estimate that likely overestimates mortality risk to tortoises. Using these estimates, we modeled the probability that a tortoise in a trampled burrow is entrapped permanently and killed as:

$$
\begin{aligned}
&Pr(tortoise\ killed|tortoise\ in\ trampled\ burrow)\\
&\qquad = Pr(severe\ burrow\ damage) \times Pr(tortoise\ killed|severe\ burrow\ damage),
\end{aligned}
$$

$$Pr(tortoise\ killed|tortoise\ in\ trampled\ burrow) = 0.25\ \times 0.20,$$

$$Pr(tortoise\ killed|tortoise\ in\ trampled\ burrow) = 0.05.$$

Total mortality risk

We calculated annual morality risk to adult tortoises from trampling by cattle by combining the three probabilities:

$$\begin{aligned} &Annual\ mortality \\ &\quad = Pr(cow\ tramples\ burrow) \times Pr(tortoise\ in\ burrow) \times \\ &\quad\quad Pr(tortoise\ killed | tortoise\ in\ burrow), \end{aligned}$$

$$Annual\ mortality = Pr(cow\ tramples\ burrow) \times 0.12 \times 0.05.$$

Because the probability that a cow tramples a burrow is linearly related to stocking rate, total annual mortality is similarly related to stocking rate (Fig. 11). Annual mortality in a cattle-grazing allotment with x stocking rate in number of head per km^2, $f(x)$, is then given by:

$$f(x) = 0.001458(x).$$

Uncertainty in the model

There are two primary sources of uncertainty in the model we developed for cattle trampling burrows inhabited by adult tortoises: model structure and parameter estimates. We made several assumptions that simplified model structure, including (1) the proportion of burrows damaged by cattle is linearly related to stocking rate, (2) adult tortoises are not at risk of being trampled by cattle when outside of burrows, and (3) cattle never kill an adult tortoise by stepping through the top of a burrow directly onto the tortoise. We likely overestimated trampling-related mortality by assuming a linear relationship between stocking rates and burrow damage, particularly for rates ≥2.5 head/km^2. Although the relationship could be asymptotic over a wide range of stocking rates (i.e., reaches a maximum level of burrow damage above some stocking rate), we used a simple linear model because we had no data to inform the nature of the relationship at higher stocking rates, and to the best of our knowledge, recent and current stocking rates in desert tortoise habitat are relatively low (<2.5 head/km^2). Generally, given the low rates of mortality associated with trampling by cattle, it is unlikely that including additional components or building a more structurally complex model would change resulting mortality rates considerably.

Where possible, parameter estimates were based on data available in the literature. Empirical data that could be used to inform several model parameters, however, were unavailable due to a lack of experimental studies and adequate sample sizes that are needed to estimate frequencies of rare events, like burrow collapse.

MODEL 3B
Quantifying effects of cattle grazing on reproduction of desert tortoises

Effects of cattle grazing on reproductive output of desert tortoises have never been studied directly. However, a number of studies have evaluated the effects of cattle grazing on vegetation communities and assessed spatial and temporal variation in reproductive output of desert tortoises. After making some general assumptions about competition for forage between cattle and tortoises, we used these data to develop a probabilistic model to quantify effects of cattle grazing on reproductive output of tortoises in areas where they co-occur.

Tortoise diet

Mojave desert tortoises, particularly those in the western Mojave Desert, depend primarily on spring annual and herbaceous perennial plants to meet their nutritional and water requirements (Jennings 1993, 2002). Tortoises are selective foragers, although specific preferences differ among populations and individuals (Jennings 1993, 2002, Esque 1994). Biomass of spring annual plants varies regionally and temporally (Beatley 1969, 1974). Extreme annual fluctuations in plant production (e.g., <0.2 kg/ha and 136.8 kg/ha in consecutive years at the same site; Beatley 1969) are thought to be associated closely with winter rainfall (approximately September through March; Beatley 1974, Turner and Randall 1989). Because of this variation in annual plant production and diversity, tortoise diets are thought to vary annually (Esque 1994).

Tortoise reproduction

Most female Mojave desert tortoises produce at least one clutch per year, but can produce up to three clutches in some years (Turner et al. 1986, 1987, Karl 1998). Annual rates of egg production seem to be relatively stable when production of spring annuals is normal or above normal, but decrease when annual plant production is well-below normal (Wallis 1999, Henen 2002). There have been few long-term studies of desert tortoise reproduction, which limits our ability to assess temporal and regional variation in annual egg production. Two studies of tortoises in the eastern Mojave Desert, however, measured egg production in 4-5 consecutive years (Turner et al. 1986, 1987, Karl 1998), and we used data from these studies to evaluate how annual egg production varies over time and with available resources.

During both studies, winter rainfall, and consequently production of spring annual plants, were below average in one year and above average in all other years. During drought years, clutch frequency decreased in both studies, the proportion of females that produced ≥1 clutch decreased in one study but not the other, and the number of eggs per clutch remained similar in all years in both studies (Table 4). These findings suggest that a threshold exists, where annual egg production remains stable when winter rains are sufficient to provide ample forage for reproductive females, but decreases in years with insufficient rainfall and annual plant production. Although we expected some kind of relationship between winter rainfall and annual egg production below the threshold, we assumed one level of reproductive output under "normal" conditions and another under "low-forage" conditions in our model because data were insufficient to elucidate the nature of the relationship.

Based on data from the two studies in the eastern Mojave, we assumed that proportion of females reproducing and clutch frequency varied over time with rainfall and amount of forage, but the number of eggs per clutch did not. Estimates for annual egg production under normal and low-forage conditions are as follows (see Table 4 for estimates of individual parameters):

$$\begin{aligned}&Annual\ egg\ production_{Normal}\\&\quad = proportion\ females\ reproducing_{Normal}\ \times (clutch\ frequency|reproduction)_{Normal}\\&\qquad \times no.eggs\ per\ clutch,\end{aligned}$$

$$Annual\ egg\ production_{Normal} = 0.953\ \times 1.824\ \times 4.067,$$

$$Annual\ egg\ production_{Normal} = 7.069.$$

$$Annual\ egg\ production_{Low} = proportion\ females\ reproducing_{LF} \times (clutch\ frequency|reproduction)_{Low} \times no.\ eggs\ per\ clutch,$$

$$Annual\ egg\ production_{Low} = 0.916 \times 1.286 \times 4.067,$$

$$Annual\ egg\ production_{Low} = 4.792.$$

Given estimates of annual egg production for normal and low-forage conditions, we needed to define these conditions, or more specifically, determine what level of annual plant production delineates the expected reproductive threshold. No studies have estimated this directly, but several studies provide information that could be used to approximate the threshold. Turner et al. (1986) measured spring annual plant biomass during some of their reproductive studies and found that mean clutch frequency was low (1.10) when plant production was very low (0.1 g/m^2), but remained relatively high (1.57-1.89) in all other years when annual plant production was ≥3.8 g/m^2. Tracy et al. (1995) used data gathered from the Beaver Dam Slope and Turner et al. (1986) to suggest that desert tortoises reduce both annual home range size and egg production when production of annual plants is <3 g/m^2. Finally, Henen (2002) suggested that a threshold exists between 2 and 4 g/m^2. Based on these data, we assumed a threshold value of 3 g/m^2.

Competition for forage

Diets of cattle and tortoise overlap approximately 37-38% in spring, and overlap much less during summer months (Coombs 1977a, Avery 1998). Like tortoises, cattle prefer annual forbs in spring when they are available. Clearly, a 450-kg cow can consume more forage per day than a 2-kg tortoise, and therefore could outcompete a tortoise when forage is limiting. In most years, however, forage is unlikely to be a limiting resource. With adequate winter rainfall, spring plants germinate and flower within 2-3 months, typically producing more biomass than could be consumed by both cattle and tortoises if present, at least with current-day stocking rates (<3 head/km^2; Tracy et al. 1995, Avery 1998, BLM 2006, 2007, *unpublished data)*. When winter rainfall is much less than normal, however, annual plant production is low, creating circumstances where forage may be limiting for the two herbivores.

How much do cows eat?

An average cow weighs approximately 454 kg and eats 1.7% of its body weight in forage daily during spring in desert grasslands (Hakkila et al. 1987, Holecheck 1988). Assuming a 100-day spring season, the average cow will eat 772 kg of forage, resulting in an average of 1.2 g of forage consumed per square meter assuming stocking rates of 1.5 head/km^2 (Tracy et al. 1995, Avery 1998, BLM 2006, 2007, *unpublished data*). Therefore, in a spring where cows are permitted to graze within the range of the desert tortoise, cows will reduce the amount of forage available to tortoises by an average of 1.2 g/m^2. In other words, if annual plant production in a grazed area = x, available forage for tortoises in this area is (x – 1.2) g/m^2. Further, if reproductive output of tortoises in an ungrazed area is reduced when annual plant production ≤3 g/m^2, reproductive output in a grazed area will be reduced when production is ≤4.2 g/m^2.

How frequently is annual plant production below the reproductive threshold?

If we had regional estimates of annual plant production for many years, we could estimate directly the number of years when forage production is low in each region; unfortunately, these data are unavailable. Alternatively, we could relate annual plant production to winter rainfall and use long-term precipitation data to estimate the frequency of years with low-forage production. Although we know that the relationship between rainfall and plant production varies across the range of the desert tortoise, limited data prevented the creation of regional models. For now, we used data from the Nevada Test Site in Rock Valley, where annual plant production was measured for 13 consecutive years and Turner and Randall (1989) modeled variation in plant production as a function of winter rainfall.

We expect that tortoises reduce their reproductive output in years when spring annual plant production ≤3 g/m^2, regardless of whether or not cattle are permitted to graze the area. Similarly, we expect that tortoises reproduce normally when plant production >4.2 g/m^2, regardless of grazing, because in these conditions forage is not a limiting resource. When plant production is between 3 and 4.2 g/m^2, however, reproductive output will be reduced in those areas where cattle are permitted to graze between March and May. To determine how frequently this level of production occurs, we used the model developed by Turner and Randall (1989) to identify the range of winter rainfall that is expected to produce 3-4.2 g/m^2 annual plant biomass, and then used long-term precipitation data to calculate how frequently precipitation between September and March falls within that range.

Based on the Turner and Randall (1989) model, when winter precipitation ranges between 69.0 and 76.9 mm, annual plant production in Rock Valley will range from 3-4.2 g/m^2 (Fig. 12). Between 1963 and 2003, winter precipitation in Rock Valley was <69 mm in 14 of 40 years and between 69 and 76.9 mm in only one of 40 years (frequency = 0.03).

Effects of cattle grazing on reproductive output of tortoises

To incorporate information from our grazing model into estimates of annual recruitment and ultimately rate of population change (λ), we needed to have estimates of egg production, hatching success, and hatchling survival. Specifically, recruitment can be defined as the number of females produced per female per year. We already calculated annual egg production (proportion of females reproducing × number of clutches × number of eggs per clutch) under normal conditions and low-forage conditions. We calculated annual recruitment under these conditions by multiplying egg production by the best available estimates of hatching success and hatchling survival for Mojave desert tortoises (hatching success = 0.61; hatchling survival to brumation = 0.87; Campbell et al. *in prep*) and dividing by two to restrict analyses to the female proportion of the population.

Annual recruitment under normal conditions (i.e., winter rainfall >3 g/m^2 and >4.2 g/m^2 in ungrazed and grazed areas, respectively):

$$Annual\ recruitment_{Normal} = \frac{(annual\ egg\ production_{Normal}) \times (hatching\ success) \times (hatchling\ survival)}{2},$$

$$Annual\ recruitment_{Normal} = \frac{(7.07) \times (0.61) \times (0.87)}{2} = 1.88\ females/female/year.$$

Annual recruitment under low-forage conditions (i.e., winter rainfall <3 g/m2 and <4.2 g/m2 in ungrazed and grazed areas, respectively):

$$Annual\ recruitment_{Low} = \frac{(annual\ egg\ production_{LF}) \times (hatching\ success) \times (hatchling\ survival)}{2},$$

$$Annual\ recruitment_{Low} = \frac{(4.79) \times (0.61) \times (0.87)}{2} = 1.27\ females/female/year.$$

Based on these estimates, we expect a 32.2% reduction in annual recruitment when little forage is available for tortoises.

Finally, we calculated the reduction in annual recruitment due to cattle grazing as the product of this reduction in recruitment and the frequency with which cattle induce low-forage conditions:

$$Annual\ reduction\ in\ recruitment\ due\ to\ grazing = (reduction\ in\ recruitment) \times\ Freq(years\ with\ reduced\ recruitment\ due\ to\ grazing),$$

$$Annual\ reduction\ in\ recruitment\ due\ to\ grazing = 0.322\ \times 0.03,$$

$$Annual\ reduction\ in\ recruitment\ due\ to\ grazing = 0.008\ (= 0.8\%).$$

Uncertainty in the model

Similar to the trampling model, there are two primary sources of uncertainty in the model: model structure and parameter estimates. We made several assumptions that simplified model structure, including (1) effects of grazing are uniform across an allotment, (2) the quantity of forage, and not the quality or type of forage available affects reproductive output, (3) stocking rates are constant at 1.5 head/km^2, and (4) no relationship between annual plant production and egg production below the reproductive threshold (i.e., two levels of egg production, one under normal conditions or better and one under low-forage conditions). Without studies that directly measure the effects of cattle grazing on reproductive output of tortoises, however, assumptions were necessary to create models.

Where possible, parameter estimates were based on data available in the literature. Empirical data that could be used to inform several model parameters, however, were unavailable due to a lack of experimental studies and adequate spatial and temporal replication in reproductive studies. We were unable to derive relationships between winter precipitation and annual plant production for additional sites, but if data were to become available, we could model the relationship between these parameters regionally and create a model for the effects of cattle grazing on reproductive output that varied across the range of the desert tortoise. Finally, we are lacking detailed information about grazing activities on particular allotments. Some allotments that are located within the range of the desert tortoise ban cattle grazing between March and May, and we would not expect reproductive output of tortoises to be affected in these areas.

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Table 1. Mean counts of ravens on BBS routes in each region surveyed between 1968 and 2007. RU = desert tortoise recovery unit.

Region	Acronym	Mean count[a]	No. routes[b]
Colorado Desert RU	CD	3.97	13
Eastern Mojave RU	EM	4.75	12
Upper Virgin River RU& Northeastern Mojave RU	UVRNE	11.22	5
East portion of Western Mojave RU	EWM	5.01	11
West portion of Western Mojave RU	WWM	19.10	15

[a] mean count of ravens on BBS routes surveyed between 1968 and 2007 with each route weighted equally regardless of when and how many times the route was surveyed.
[b] Only included routes if >1/3 of the route was within the region. Routes that spanned more than one region were included in both.

Table 2. Density estimates of successful nests in each region extrapolated from Knight and Kawashima (1993), average area containing one successful nest, and average annual mortality from breeding ravens nesting on natural structures.

Region	Nest density (nests/km^2)	Average area containing one nest (km^2)	Average annual mortality
CD	0.005	196	0.002
EM	0.005	196	0.002
UVRNE	0.013	78	0.005
EWM	0.005	196	0.002
WWM	0.020	49	0.008

Table 3. Density estimates of successful nests in each region extrapolated from Knight and Kawashima (1993), average area containing one successful nest, and average annual mortality from breeding ravens nesting in utility corridors.

Region	Nest density (nests/km^2)	Average area containing one nest (km^2)	Average annual mortality
CD	0.170	5.90	0.067
EM	0.170	5.90	0.067
UVRNE	0.424	2.36	0.167
EWM	0.170	5.90	0.067
WWM	0.678	1.47	0.268

Table 4. Data from reproductive studies of desert tortoises in the eastern Mojave Desert in 1983-1986 and 1991-1995 (Turner et al. 1986, 1987 and Karl 1998). % Normal precipitation = percent of long-term normal winter precipitation (October- March). Clutch frequency was measured only for those females that produced ≥1 clutch. Mean proportion of females reproducing and mean clutch frequency were calculated across sites for all years with above-average precipitation and all years with below-average precipitation. Mean number of eggs per clutch was calculated across both sites and all years.

Site	Year	% Normal precipitation	Proportion reproducing	Clutch frequency	No. eggs per clutch	Source
Goffs	1983	176	1.00	1.90	4.11	Turner et al. 1986
Goffs	1984	203	0.96	1.62	4.30	Turner et al. 1986
Goffs	1985	136	1.00	1.75	5.14	Turner et al. 1986
Goffs	1986	55	1.00	1.21	4.00	Turner et al. 1987
Upper Ward Valley	1991	133	1.00	1.89	4.22	Karl 1998
Upper Ward Valley	1992	334	0.93	2.00	3.63	Karl 1998
Upper Ward Valley	1993	405	0.90	1.89	3.71	Karl 1998
Upper Ward Valley	1994	76	0.82	1.38	3.90	Karl 1998
Upper Ward Valley	1995	278	0.93	1.72	3.93	Karl 1998
Mean (above-normal precipitation)			**0.95**	**1.82**		
Mean (below-normal precipitation)			**0.92**	**1.29**		
Mean (all years)					**4.07**	

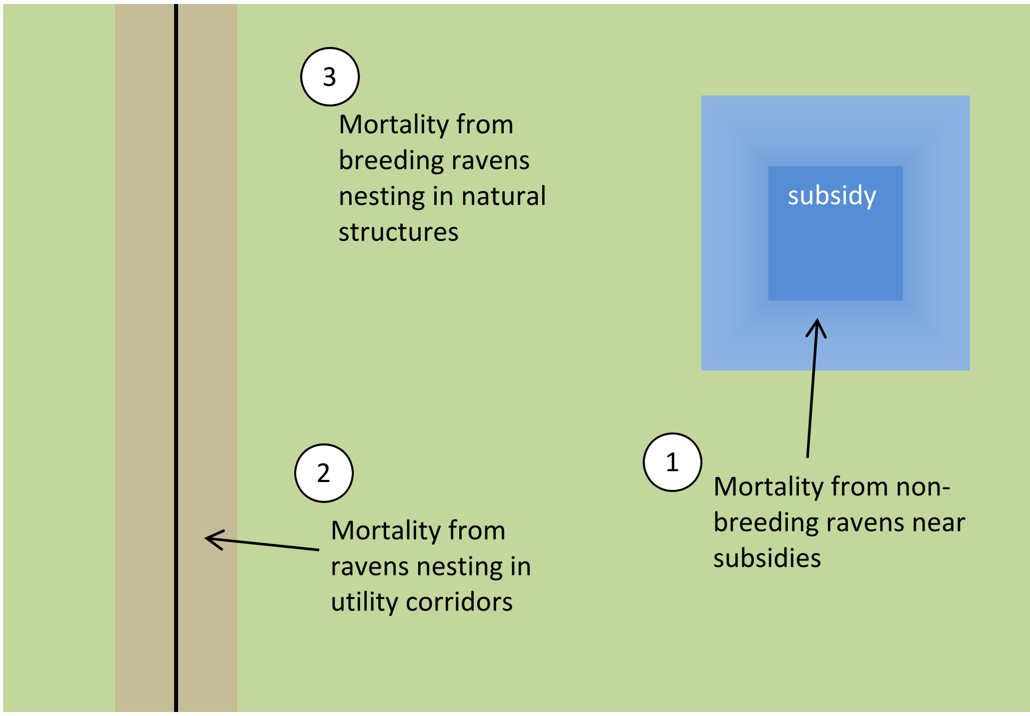


Figure 1. Three rates of annual mortality for juvenile tortoises due to predation from 1) non-breeding ravens near anthropogenic subsidies (blue), 2) breeding ravens that nest in utility corridors (brown), and 3) breeding ravens that nest outside of utility corridors in natural structures (green).

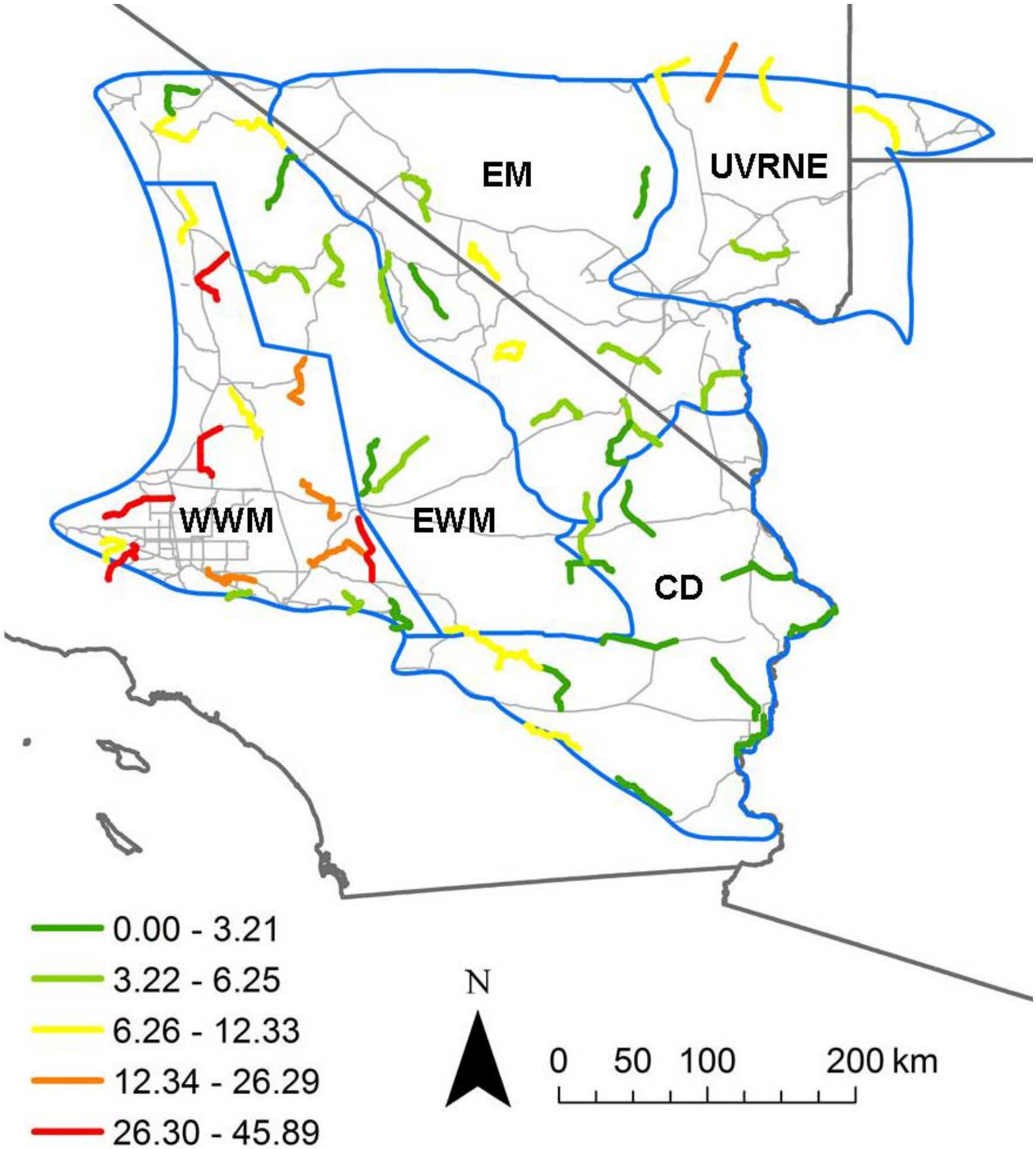


Figure 2. Mean number of ravens observed on BBS routes across all years each route was surveyed between 1968 and 2007. Proposed regions, which are largely based on desert tortoise recovery units, are in blue, with acronyms provided in Table 1.

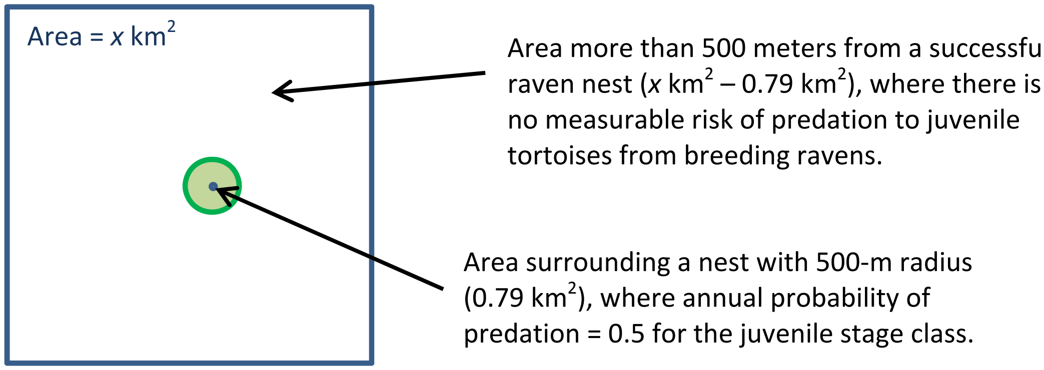


Figure 3. Predation risk to juvenile tortoises from breeding ravens nesting in a natural structure.

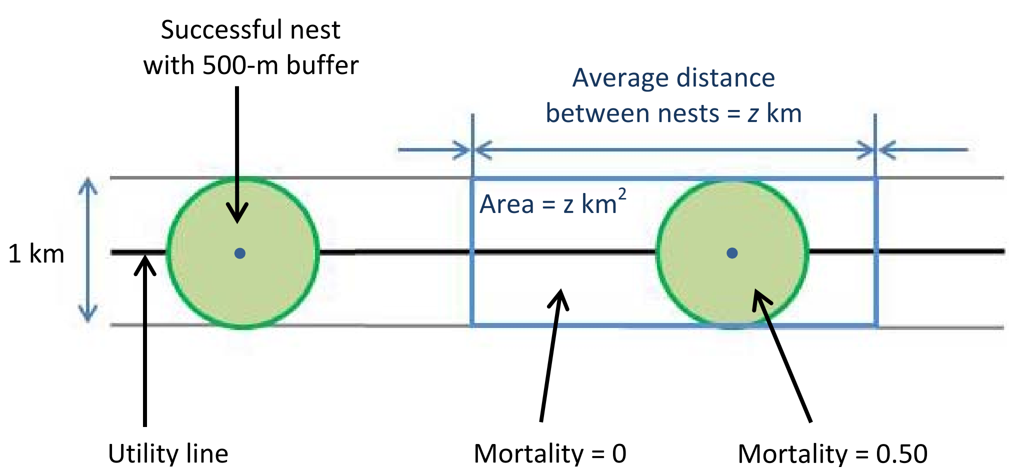


Figure 4. Predation risk to juvenile tortoises from breeding ravens nesting in utility corridors.

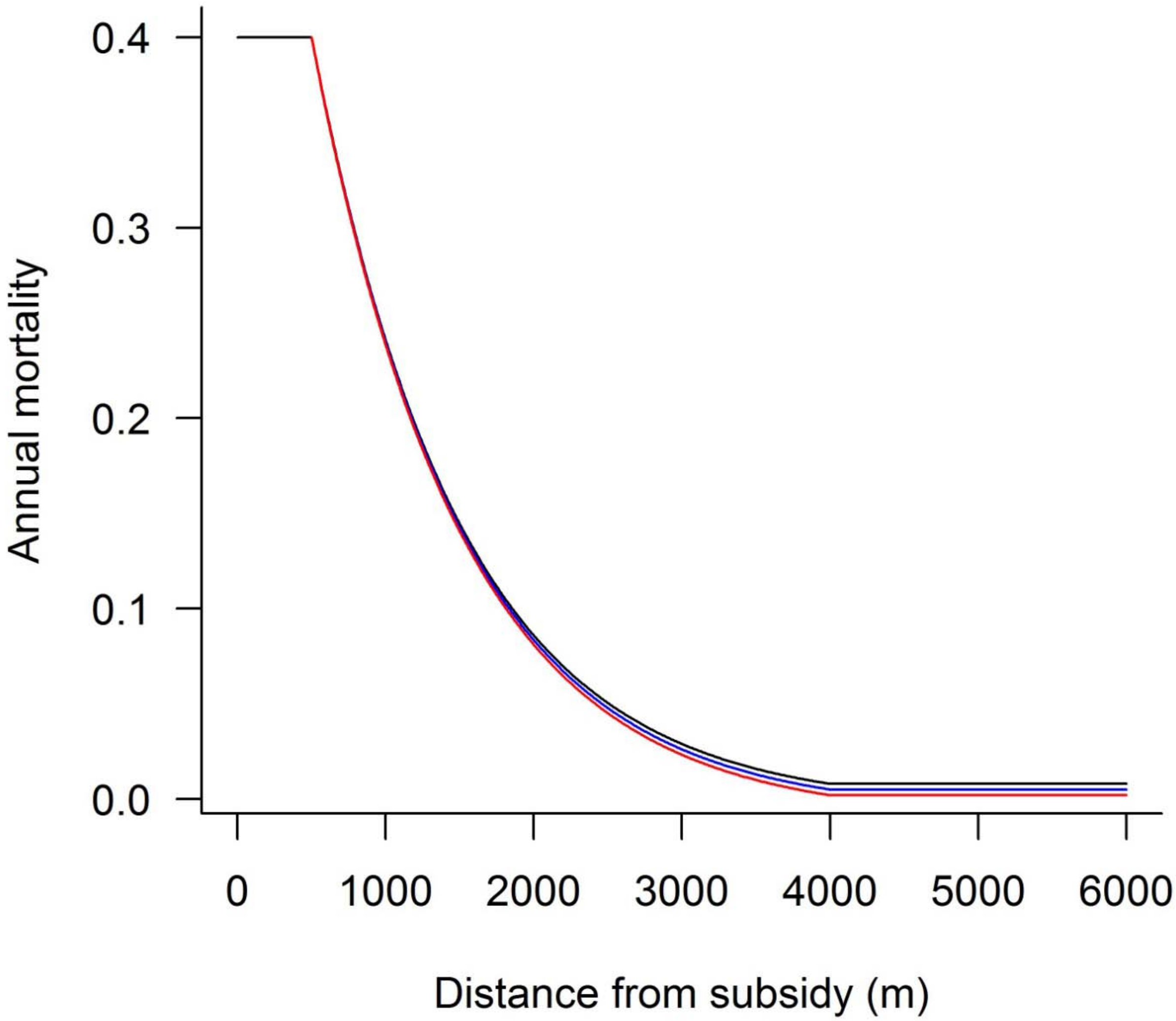


Figure 5. Annual mortality of juvenile tortoises from non-breeding ravens as a function of distance to anthropogenic subsidies in the WWM region (black), the UVRNE region (blue), and the EWM, CD, and EM regions (red). Mortality rates reach background levels ≥4 km from an anthropogenic subsidy.

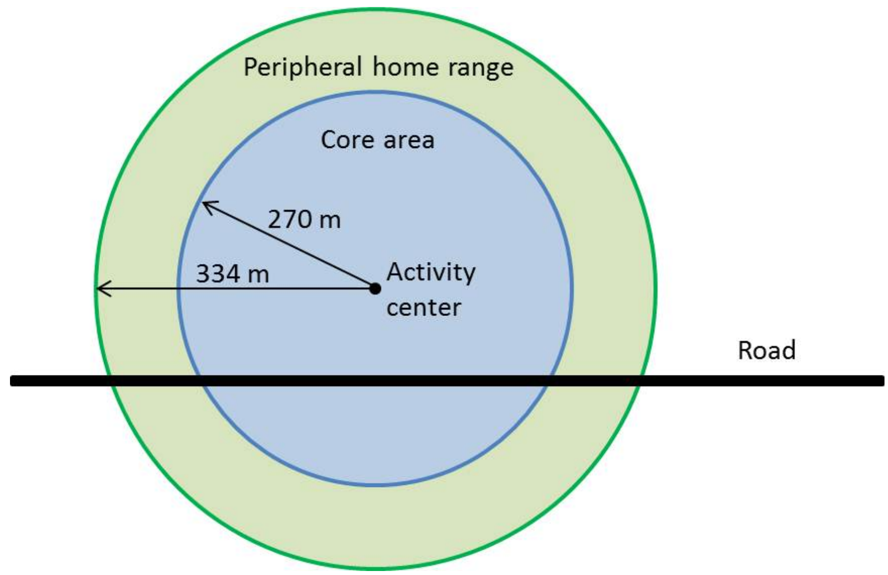


Figure 6. Generalized probability surface for the activity of a tortoise living near a road. A tortoise is expected to spend 95% of the active season in the core area (blue) and 5% in the peripheral home range outside of the core area (green).

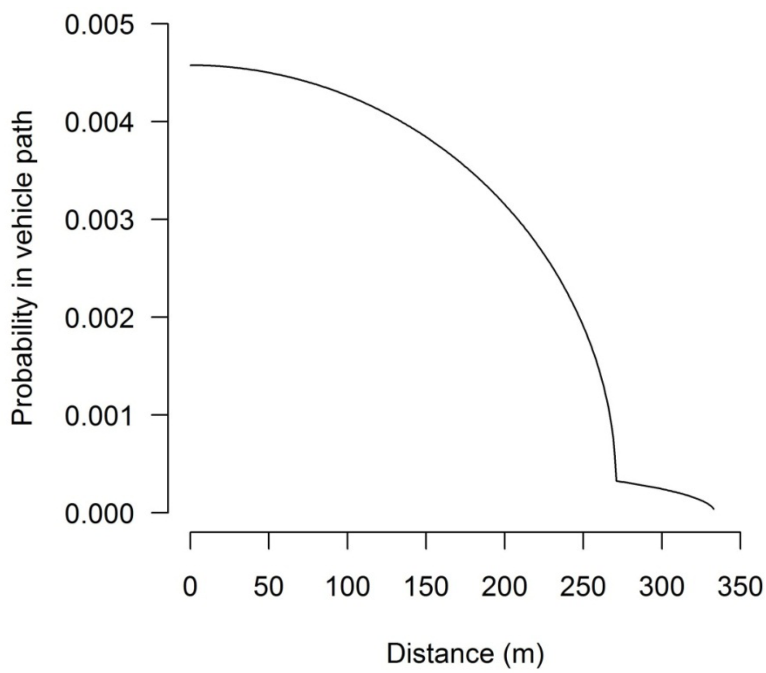


Figure 7. Probability a tortoise is in a vehicle path as a function of the distance between the vehicle path and the activity center of the tortoise.

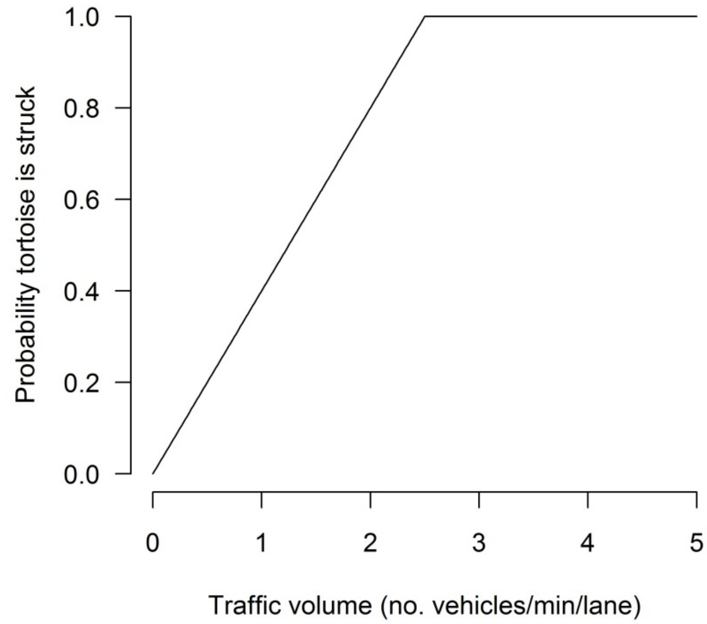


Figure 8. Probability that a tortoise in a vehicle path is struck as a function of traffic volume.

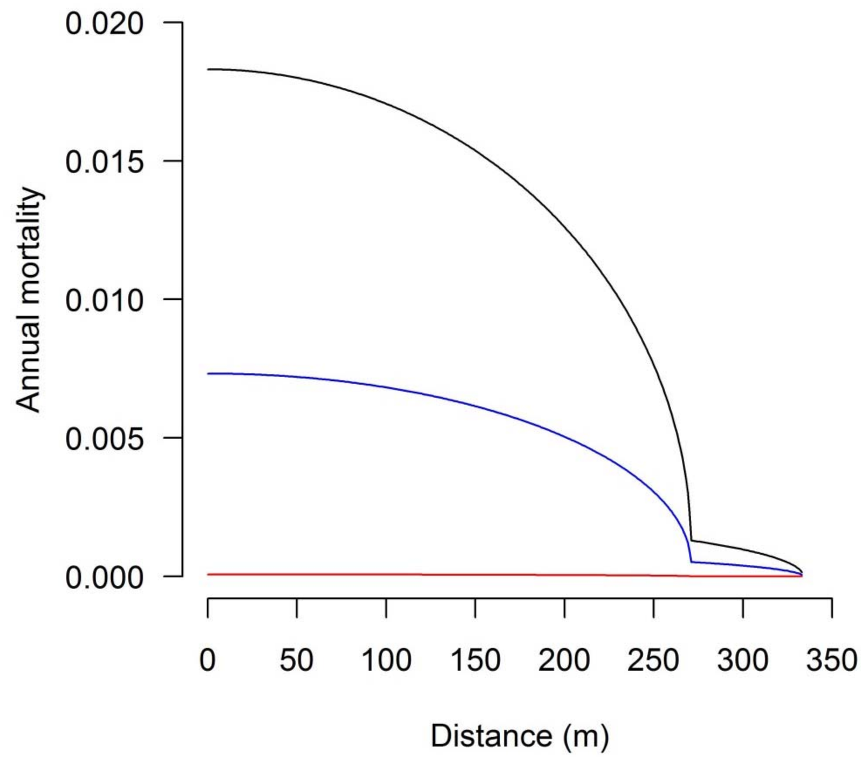


Figure 9. Annual mortality of adult tortoises as a function of the distance between the activity center of the tortoise and a four-lane road with high traffic volume (black; 20 vehicles/min/lane), a two-lane road with moderate traffic volume (blue; 2 vehicles/min/lane), and a two-lane road with low traffic volume (red; 0.02 vehicles/min/lane).

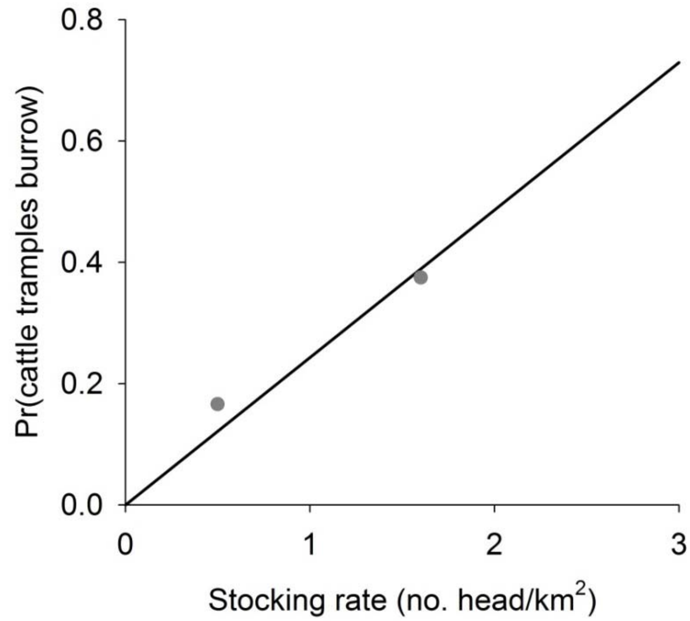


Figure 10. Probability that a tortoise burrow is damaged by cattle as a function of stocking rate. Points represent estimates from Avery and Neibergs (1997) and Woodman et al. (1998).

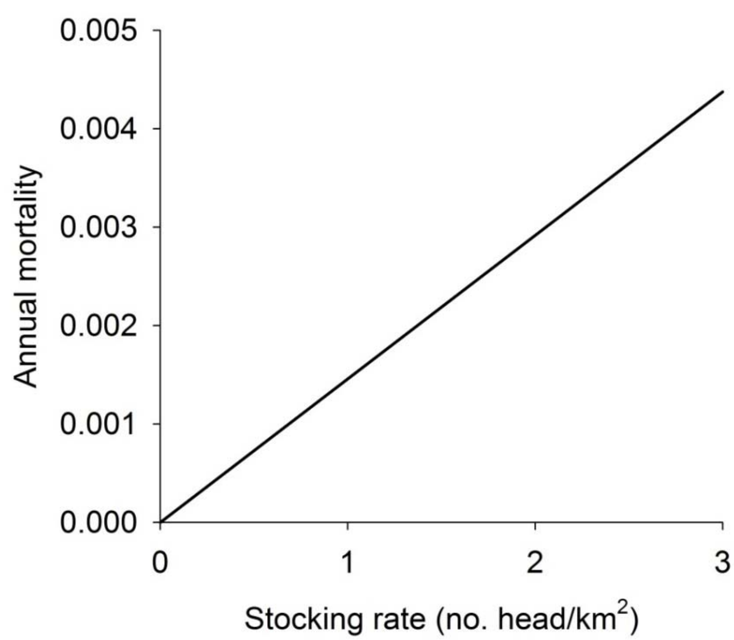


Figure 11. Estimated annual mortality of adult tortoises from trampling by cattle as a function of stocking rate.

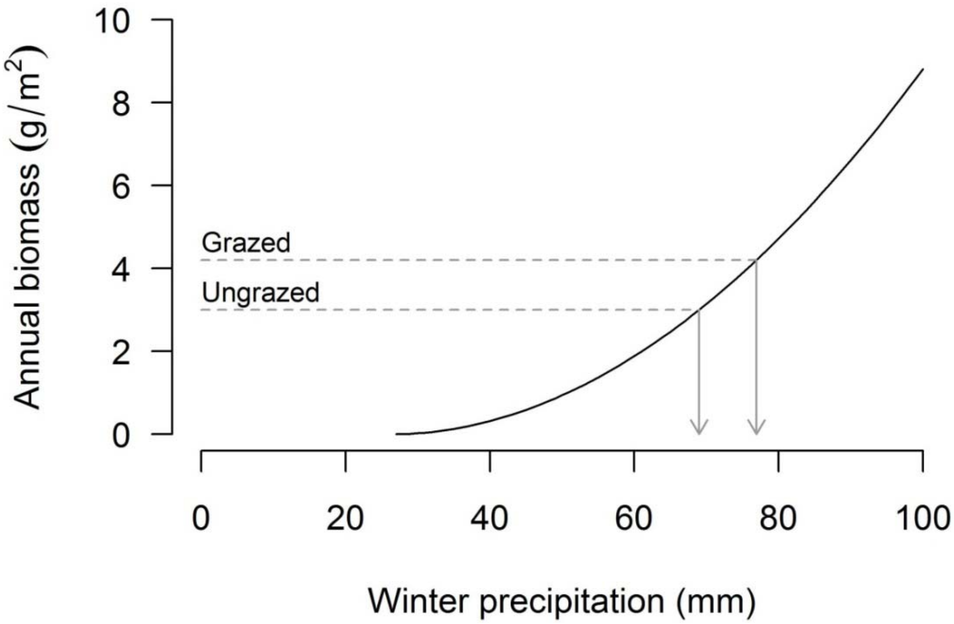


Figure 12. Spring annual plant biomass in Rock Valley, NV as a function of winter precipitation (Sept-March), 1964-1976 (from Turner and Randall 1989). Dotted horizontal lines represent thresholds of annual plant production in areas grazed by cattle in the spring (4.2 g/m^2) and ungrazed areas (3 g/m^2) below which tortoises reduce reproductive output. Arrows indicate the amount of winter precipitation needed to reach each threshold level.

APPENDIX C:
Table of Monitoring Metrics

Threats	Stresses	Possible Actions	Implementation Metric	Effectiveness Metric 1 (Is the action effective at ameliorating the threat?)	Effectiveness Metric 2 (Is the action effective at ameliorating stress caused by the threat?)	Effectiveness Metric 3 (Was ameliorating the threat/stress effective at meeting recovery criteria?)
Agriculture	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Deacresed area of CHU/DWMA/RU in agriculture (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises within ag areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Agriculture	Habitat Loss	Restore Habitat (2.6)	Area and location of habitat restoration within ag lands	Decreased area of CHU/DWMA/RU in agriculture	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Agriculture	Population fragmentation	Restore Habitat (2.6)	Area and location of habitat restoration within ag lands	Decreased area of CHU/DWMA/RU in agriculture	Increased movement patterns and/or rate of colonization/extiripation at local and regional scales.	Distribution throughout each TCA is increasing (i.e., ψ > 0); increased population densities
Agriculture	population and stochastic effects	Restore Habitat (2.6)	Area and location of habitat restoration within ag lands	Decreased area of CHU/DWMA/RU in agriculture	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Altered hydrology	Loss of shelter and breeding sites	Restore Habitat (2.6)	Area and location of restoration due to altered hydrology	Decreased geospatial measure of altered hydrology	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Altered hydrology	Nutritional compromise	Restore Habitat (2.6)	Area and location of restoration due to altered hydrology	Decreased geospatial measure of altered hydrology	options; Plant species composition, species richness, or % cover of native annuals	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Aqueducts	Entrapment/burial	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased area/lenth of aqueduct in CHU/DWMA/RU (unfenced): increased area fenced	Decreased incidence of trauma to live tortoisesdue to aqueducts	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Disease	Disease	Manage disease in captive population (permitting) (2.2)	Number of permitting programs implemented for pet tortoises	Decreased incidence/density of disease in captive population	Decreased incidence of disease; Increased population densities	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Disease	Disease	Manage disease in wild population (2.2)	Locations of disease management activities	Decreased Incidence/density of disease in wild populations	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Drought	Dehydration	Restore Habitat (2.6)	habitat restoration due to drought	N/A	Decreased incidence of trauma to live tortoises due to dehydration	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Drought	Nutritional compromise	Restore Habitat (2.6)	Area and location of habitat restoration due to drought	N/A	options; Plant species composition, species richness, or % cover of native annuals	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	Burning or smoke inhalation	Environmental Education (2.3)	environmental education activities undertaken to counter burning caused by fire	Decreased area of fire threat potential	Decreased incidence of trauma to live tortoises due to burning or smoke inhalation	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Fire Potential	smoke inhalation	planning and implementation (2.1)	management planning activities	Decreased area of fire threat potential	tortoises due to burning or smoke inhalation	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	smoke inhalation	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to fire	tortoises due to burning or smoke inhalation	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	Loss of shelter and breeding sites	Environmental Education (2.3)	environmental education activities undertaken to counter loss of shelter/breeding sites cause by fire	Decreased area of fire threat potential	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	and breeding sites	planning and implementation (2.1)	management planning activities	Decreased area of fire threat potential	caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	and breeding sites	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to fire	caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	Nutritional compromise	Environmental Education (2.3)	environmental education activities undertaken to counter nutritional compromise cause by fire	Decreased area of fire threat potential	Measure of improved nutritional options; Plant species composition, species richness, or % cover of invasive	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	Nutritional compromise	Fire management planning and implementation (2.1)	Location of fire management planning activities	Decreased area of fire threat potential	options; Plant species composition, species richness, or % cover of invasive	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Fire Potential	Nutritional compromise	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to fire	options; Plant species composition, species richness, or % cover of invasive	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Injury	Control dogs (2.14)	Locations of activities related to controlling free-roaming dogs	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Injury	Decrease predator access to human subsidies (2.14)	related to reducing predator access to human subsidies	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Injury	Environmental Education (2.3)	environmental education activities undertaken to counter injury caused by free-	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Injury	human barriers (wildland-urban interface) (2.7)	human barriers at the wildland-urban interface	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Predation	Control dogs (2.14)	Locations of activities related to controlling free-roaming dogs	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Free-roaming Dogs	Predation	Decrease predator access to human subsidies (2.14)	related to reducing predator access to human subsidies	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Predation	Environmental Education (2.3)	environmental education activities undertaken to counter predation caused by free-roaming dogs	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Free-roaming Dogs	Predation	human barriers (wildland-urban interface) (2.7)	human barriers at the wildland-urban interface	Decreased number or density of free-roaming dogs within the area	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Garbage and Dumping	Injury	Environmental Education (2.3)	environmental education activities undertaken to counter injury caused by littering and dumping	Decreased amount of garbage/dumping within the CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to garbage or dumping	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Garbage and Dumping	Injury	Increase law enforcement (2.4)	Total number and location of LE	with the public related to littering/dumping	Decreased incidence of trauma to live tortoises due to garbage or dumping	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Garbage and Dumping	Injury	Restore habitat (garbage clean up)	Locations of garbage clean-up activities	Decreased amount of garbage/dumping within the CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to garbage or dumping	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Geothermal Energy Development	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	CHU/DWMA/RU in geothermal energy development (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises due to geothermal energy developments	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Grazing	Crushing	Remove grazing (close allotments)	Locations of retired allotments	grazing within the CHU/DWMA/RU	tortoises within previously grazed areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Grazing	Entrapment/burial	Remove grazing (close allotments)	Locations of retired allotments	grazing within the CHU/DWMA/RU	tortoises within previously grazed areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Grazing	and breeding sites	Remove grazing (close allotments)	Locations of retired allotments	grazing within the CHU/DWMA/RU	caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Grazing	Loss of shelter and breeding sites	Restore Habitat (2.6)	Area and location of allotment habitat restoration projects	Decreased area that is open to grazing within the CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Grazing	Nutritional compromise	Remove grazing (close allotments)	Locations of retired allotments	Decreased area that is open to grazing within the CHU/DWMA/RU	options; Plant species composition, species richness, or % cover of invasive vs. native annuals	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Grazing	Nutritional compromise	Restore Habitat (2.6)	Area and location of allotment habitat restoration projects	Decreased area that is open to grazing within the CHU/DWMA/RU	options; Plant species composition, species richness, or % cover of invasive vs. native annuals	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Historical Fire	and breeding sites	Restore Habitat (2.6)	post-fire habitat restoration	Decreased area of fire threat potential	caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Historical Fire	Nutritional compromise	Restore Habitat (2.6)	Area and location of post-fire habitat restoration	Decreased area of fire threat potential	options; Plant species composition, species richness, or % cover of invasive	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	roads (travel management plan) (5.2.2)	roads; locations of travel management planning efforts	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	Environmental Education (2.3)	environmental education activities undertaken to counter collection of wild tortoises caused by	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	Increase law enforcement (2.4)	Total number and location of LE	with the public related to collection of tortoise from the wild	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	human barriers (preserves) (2.7)	human barriers around preserves	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	human barriers (wildland-urban interface) (2.7)	human barriers at the wildland-urban interface	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	mulching-roads) (2.3.6)	Locations of vertical mulching	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	Sign and fence protected areas (2.8)	Length and location of fence and signs around protected area	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Collection (B1)	Sign Designated Routes (2.1.8)	Locations of signs along designated routes	N/A	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Deliberate maiming or killing (B2)	Environmental Education (2.3)	environmental education activities undertaken to counter deliberate maiming and killing caused by	N/A	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Deliberate maiming or killing (B2)	Increase law enforcement (2.4)	Total number and location of LE	with the public related to deliberate maiming/killing of tortoises	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	maiming or killing (B2)	human barriers (preserves) (2.7)	human barriers around preserves	N/A	tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	Deliberate maiming or killing (B2)	human barriers (wildland-urban interface) (2.7)	human barriers at the wildland-urban interface	N/A	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	maiming or killing (B2)	mulching-roads) (2.3.6)	Locations of vertical mulching	N/A	tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Human Access	Deliberate maiming or killing (B2)	Sign and fence protected areas (2.8)	Length and location of fence and signs around protected area	N/A	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Human Access	maiming or killing (B2)	Sign Designated Routes (2.1.8)	Locations of signs along designated routes	N/A	tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Invasive Plants	Dehydration	Restore Habitat (2.6)	Area and location of activities to restore invasive infestations	invasive plants; percent cover of invasive plants within the CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to dehydration	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Invasive Plants	Nutritional compromise	Restore Habitat (2.6)	habitat restoration/weed management activities	invasive plants; percent cover of invasive plants within the CHU/DWMA/RU	options; Plant species composition, species richness, or % cover of invasive	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Landfills	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased number/area of landfills within the CHU/DWMA/RU (unfenced); increased number/area fenced	Decreased incidence of trauma to live tortoises due to landfill activities	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Landfills	Crushing	Landfill management	Locations of landfill management plans	landfills within the CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to landfill activities	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Landfills	Habitat Loss	Landfill management	Locations of landfill management plans	Decreased number/area of landfills within the CHU/DWMA/RU	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Military Operations	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing on military installations	N/A	Decreased incidence of trauma to live tortoises on military installations	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Mineral Development	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased number or density of open/active mines within the CHU/DWMA/RU (unfenced); increased number/density fenced.	Decreased incidence of trauma to live tortoises within mining areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Mineral Development	Crushing	Withdraw mining (2.12)	Number and location of closed/withdrawn mines	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Decreased incidence of trauma to live tortoises within mining areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Mineral Development	Entrapment/burial	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased number or density of open/active mines within the CHU/DWMA/RU (unfenced); increased number/density fenced.	Decreased incidence of entrapment of live tortoises within mining areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Mineral Development	Entrapment/burial	Withdraw mining (2.12)	Number and location of closed/withdrawn mines	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Decreased incidence of entrapment of live tortoises within mining areas	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Mineral Development	Habitat Loss	Restore Habitat (2.6)	Area and location of mine/habitat restoration	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Mineral Development	Habitat Loss	Withdraw mining (2.12)	Number and location of closed/withdrawn mines	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Mineral Development	Population fragmentation	Restore Habitat (2.6)	Area and location of mine/habitat restoration	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Increased movement patterns and/or rate of colonization/extirpation at local and regional scales.	Distribution throughout each TCA is increasing (i.e., $\psi > 0$); increased population densities
Mineral Development	Population fragmentation	Withdraw mining (2.12)	Number and location of closed/withdrawn mines	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Increased movement patterns and/or rate of colonization/extirpation at local and regional scales.	Distribution throughout each TCA is increasing (i.e., $\psi > 0$); increased population densities
Mineral Development	population and stochastic effects	Restore Habitat (2.6)	Area and location of mine/habitat restoration	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities
Mineral Development	population and stochastic effects	Withdraw mining (2.12)	Number and location of closed/withdrawn mines	Decreased number or density of open/active mines within the CHU/DWMA/RU.	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities
Motor Vehicles Off Route	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by motor vehicles off	Decreased area of unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities
Motor Vehicles Off Route	Crushing	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to motor vehicles off route	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities
Motor Vehicles Off Route	Crushing	Install and maintain human barriers (wildland-urban interface) (2.7)	Length and location of human barriers at the wildland-urban interface	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU (at the wildland-urban interface)	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities
Motor Vehicles Off Route	Crushing	Restore roads (vertical mulching-roads) (2.3.6)	Locations of vertical mulching	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities
Motor Vehicles Off Route	Crushing	Sign and fence protected areas (2.8)	fence and signs around protected areas where unauthorized OHV had been a problem	Decreased area of unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., $\lambda > 1$); increased population densities

Motor Vehicles Off Route	Crushing	Sign Designated Routes (2.1.8)	Locations of signed designated routes	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Entrapment/burial	Environmental Education (2.3)	environmental education activities undertaken to counter burial caused by motor vehicles off route	Decreased area of unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Entrapment/burial	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to motor vehicles off route	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Entrapment/burial	Install and maintain human barriers (wildland-urban interface) (2.7)	Length and location of human barriers at the wildland-urban interface	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU (at the wildland-urban interface)	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Entrapment/burial	Restore roads (vertical mulching-roads) (2.3.6)	Locations of vertical mulching	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Entrapment/burial	Sign and fence protected areas (2.8)	fence and signs around protected areas where unauthorized OHV had been a problem	Decreased area of unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Entrapment/burial	Sign Designated Routes (2.1.8)	Locations of signed designated routes	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles Off Route	Loss of shelter and breeding sites	Environmental Education (2.3)	environmental education activities undertaken to counter habitat degradation caused by motor	Decreased area of unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Motor Vehicles Off Route	Loss of shelter and breeding sites	Install and maintain human barriers (wildland-urban interface) (2.7)	Length and location of human barriers at the wildland-urban interface	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU (at the wildland-urban interface)	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Motor Vehicles Off Route	Loss of shelter and breeding sites	Restore Habitat (2.6)	Area and location of restoring areas of unauthorized OHV use	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Motor Vehicles Off Route	Loss of shelter and breeding sites	Restore roads (vertical mulching-roads) (2.3.6)	Locations of vertical mulching	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving

Motor Vehicles Off Route	Loss of shelter and breeding sites	Sign and fence protected areas (2.8)	fence and signs around protected areas where unauthorized OHV had been a problem	Decreased area of unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Motor Vehicles Off Route	Loss of shelter and breeding sites	Sign Designated Routes (2.1.8)	Locations of signed designated routes	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Motor Vehicles on Paved Roads	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by motor vehicles on	N/A	Decreased incidence of trauma to live tortoises due to motor vehicles on paved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Paved Roads	Crushing	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to motor vehicles on paved roads	Decreased incidence of trauma to live tortoises due to motor vehicles on paved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Paved Roads	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	N/A	Decreased incidence of trauma to live tortoises due to motor vehicles on paved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Paved Roads	Crushing	Speed limits (2.5)	Locations where speed limits have been designated	Decreased number of speeding citations issued or average speed on road	Decreased incidence of trauma to live tortoises due to motor vehicles on paved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Paved Roads	Deliberate maiming or killing (B2)	Environmental Education (2.3)	environmental education activities undertaken to counter deliberate maiming and killing caused by motor vehicles on paved	N/A	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Paved Roads	Deliberate maiming or killing (B2)	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to motor vehicles on paved roads	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Unpaved Roads	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by motor vehicles on	N/A	Decreased incidence of trauma to live tortoises due to vehicles on unpaved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Unpaved Roads	Crushing	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to motor vehicles on unpaved roads	Decreased incidence of trauma to live tortoises due to vehicles on unpaved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Motor Vehicles on Unpaved Roads	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased length of unfenced unpaved road within the CHU/DWMA/RU; decreased length of open/designated routes within the CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to vehicles on unpaved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Unpaved Roads	Crushing	Speed limits (2.5)	Locations where speed limits have been designated	Decreased number of speeding citations issued or average speed on road	Decreased incidence of trauma to live tortoises due to vehicles on unpaved roads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Unpaved Roads	Deliberate maiming or killing (B2)	Environmental Education (2.3)	environmental education activities undertaken to counter deliberate maiming and killing caused by motor vehicles on unpaved	N/A	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Motor Vehicles on Unpaved Roads	Deliberate maiming or killing (B2)	Increase law enforcement (2.4)	Total number and location of LE	with the public related to deliberate maiming/killing of tortoises	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Collection (B1)	Environmental Education (2.3)	environmental education activities undertaken to counter collection of wild tortoises associated with non-motorized	Decreased number of campground/recreation sites within the CHU/DWMA/RU	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Collection (B1)	Increase law enforcement (2.4)	Total number and location of LE	with the public related to collection of tortoise from the wild	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Collection (B1)	Sign and fence protected areas (2.8)	Length and location of fence and signs around protected area	Decreased number of campground/recreation sites within the CHU/DWMA/RU	Decreased incidence of collection of live tortoises	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by non-motorized recreation	Decreased number of campground/recreation sites within the CHU/DWMA/RU	Decreaed incidence of trauma to live tortoises due to non-motorized rec activities	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Crushing	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to non-motorized recreation	Decreaed incidence of trauma to live tortoises due to non-motorized rec activities	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Crushing	Sign and fence protected areas (2.8)	Length and location of fence and signs around protected area	Decreased number of campground/recreation sites within the CHU/DWMA/RU	Decreaed incidence of trauma to live tortoises due to non-motorized rec activities	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Non-motorized Recreation	Deliberate maiming or killing (B2)	Environmental Education (2.3)	environmental education activities undertaken to counter deliberate maiming and killing associated with non-motorized	Decreased number of campground/recreation sites within the CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Non-motorized Recreation	Deliberate maiming or killing (B2)	Increase law enforcement (2.4)	Total number and location of LE	with the public related to deliberate maiming/killing of tortoises	Decreased incidence of trauma to live tortoises due to deliberate maiming or killing	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
OHV Events	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by OHV events	N/A	Decreased incidence of trauma to live tortoises due to OHV events	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
OHV Events	Crushing	Restrict OHV events (2.10)	Locations where OHV events have been restricted	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
OHV Events	Entrapment/burial	Environmental Education (2.3)	environmental education activities undertaken to counter entrapment/burial caused by OHV events	N/A	Decreased incidence of trauma to live tortoises due to OHV events	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
OHV Events	Entrapment/burial	Restrict OHV events (2.10)	Locations where OHV events have been restricted	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
OHV Events	Loss of shelter and breeding sites	Restrict OHV events (2.10)	Locations where OHV events have been restricted	unauthorized/illegal/off-route OHV activity in CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Oil & Gas Development	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	CHU/DWMA/RU in oil & gas development (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises due to oil & gas developments	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Open OHV Area Use	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by open OHV area use	N/A	Decreased incidence of trauma to live tortoises due to open OHV area use	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Open OHV Area Use	Crushing	Install and maintain tortoise barriers (open OHV areas) (2.7)	tortoise fence installed around open OHV areas	Decreased area of open OHV activity in CHU/DWMA/RU (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Open OHV Area Use	Entrapment/burial	Environmental Education (2.3)	environmental education activities undertaken to counter deliberate maiming and killing caused by open OHV area use	N/A	Decreased incidence of trauma to live tortoises due to open OHV area use	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Open OHV Area Use	Entrapment/burial	Install and maintain tortoise barriers (open OHV areas) (2.7)	tortoise fence installed around open OHV areas	Decreased area of open OHV activity in CHU/DWMA/RU (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises due to motor vehicles off route	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Paved Roads	Population fragmentation	Connect habitat (culverts/underpasses) (2.11)	Locations of culverts and underpasses	within the CHU/DWMA/RU (with/without culverts/underpasses)	Increased movement patterns and/or rate of colonization/extirpation at local and regional scales.	Distribution throughout each TCA is increasing (i.e., ψ > 0); increased population densities
Paved Roads	population and stochastic effects	Connect habitat (culverts/underpasses) (2.11)	Locations of culverts and underpasses	within the CHU/DWMA/RU (with/without culverts/underpasses)	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Potential Conversion/Private Parcels	Habitat Loss	Land acquisition (2.9)	Area and location of land acquired	Decreased area of CHU/DWMA/Habitat that's private-land	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Potential Conversion/Private Parcels	Population fragmentation	Land acquisition (2.9)	Area and location of land acquired	Decreased area of CHU/DWMA/Habitat that's private-land	Increased movement patterns and/or rate of colonization/extirpation at local and regional scales.	Distribution throughout each TCA is increasing (i.e., ψ > 0); increased population densities
Potential Conversion/Private Parcels	population and stochastic effects	Land acquisition (2.9)	Area and location of land acquired	Decreased area of CHU/DWMA/Habitat that's private-land	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Predators (non-raven)	Injury	Decrease predator access to human subsidies (2.14)	related to reducing predator access to human subsidies	Decreased measure of non-raven predator (coyote) presence within the CHU/RU/DWMA	Decreased icidence of trauma to live tortoises due to non-raven predators	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Predators (non-raven)	Injury	Environmental Education (2.3)	environmental education activities undertaken to counter injury caused by non-raven predators	Decreased measure of non-raven predator (coyote) presence within the CHU/RU/DWMA	Decreased icidence of trauma to live tortoises due to non-raven predators	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Predators (non-raven)	Injury	Targeted predator control (2.14)	Location of targeted non-raven predator control activities	Number of predators removed within the area	Decreased icidence of trauma to live tortoises due to non-raven predators	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Predators (non-raven)	Predation	Decrease predator access to human subsidies (2.14)	related to reducing predator access to human subsidies	Decreased measure of non-raven predator (coyote) presence within the CHU/RU/DWMA	Decreased incidence of trauma to live tortoises due to free-roaming dogs	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Predators (non-raven)	Predation	Environmental Education (2.3)	environmental education activities undertaken to counter predation caused by non-raven predators	Decreased measure of non-raven predator (coyote) presence within the CHU/RU/DWMA	Decreased icidence of trauma to live tortoises due to non-raven predators	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Predators (non-raven)	Predation	Targeted predator control (2.14)	Location of targeted non-raven predator control activities	Number of predators removed within the area	Decreased icidence of trauma to live tortoises due to non-raven predators	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Railroads	Crushing	Connect habitat (culverts/underpasses) (2.11)	Locations of installed culverts/underpasses	Increased area/length of railroads within the CHU/DWMA/RU (with culverts/underpasses)	Decreased incidence of trauma to live tortoises due to railroads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Railroads	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased area/length of railroads within the CHU/DWMA/RU (fenced); increased fenced length/area	Decreased incidence of trauma to live tortoises due to railroads	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Railroads	Habitat Loss	Restore Habitat (2.6)	Locations of where habitat restoration has taken place on former railroads	Decreased area/length of railroads within the CHU/DWMA/RU	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Railroads	Population fragmentation	Connect habitat (culverts/underpasses) (2.11)	Locations of installed culverts/underpasses	Increased area/length of railroads within the CHU/DWMA/RU (with culverts/underpasses)	Increased movement patterns and/or rate of colonization/extiripation at local and regional scales.	Distribution throughout each TCA is increasing (i.e., ψ > 0); increased population densities
Railroads	Population fragmentation	Restore Habitat (2.6)	Locations of where habitat restoration has taken place on former railroads	Decreased area/length of railroads within the CHU/DWMA/RU	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Railroads	population and stochastic effects	Connect habitat (culverts/underpasses) (2.11)	Locations of installed culverts/underpasses	Increased area/length of railroads within the CHU/DWMA/RU (with culverts/underpasses)	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Railroads	population and stochastic effects	Restore Habitat (2.6)	habitat restoration has taken place on former railroads	Decreased area/length of railroads within the CHU/DWMA/RU	Increased area of occupany and/or population abundance across CHU/DWMA/RU	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Ravens	Injury	Decrease predator access to human subsidies (2.14)	related to reducing predator access to human subsidies	Decreased measure of raven presence within the CHU/RU/DWMA	Decreased incidence of trauma to live tortoises due to ravens	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Ravens	Injury	Environmental Education (2.3)	environmental education activities undertaken to counter injury caused by ravens	Decreased measure of raven presence within the CHU/RU/DWMA	Decreased incidence of trauma to live tortoises due to ravens	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Ravens	Injury	Targeted predator control (2.14)	Location of targeted raven control activities	Number of ravens removed within the area	Decreased incidence of trauma to live tortoises due to ravens	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Ravens	Predation	Decrease predator access to human subsidies (2.14)	related to reducing predator access to human subsidies	Decreased measure of raven presence within the CHU/RU/DWMA	Decreased incidence of trauma to live tortoises due to ravens	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Ravens	Predation	Environmental Education (2.3)	environmental education activities undertaken to counter predation caused by	Decreased measure of raven presence within the CHU/RU/DWMA	Decreased incidence of trauma to live tortoises due to ravens	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Ravens	Predation	Targeted predator control (2.14)	Location of targeted raven control activities	Number of ravens removed within the area	Decreased incidence of trauma to live tortoises due to ravens	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Solar Energy Development	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	CHU/DWMA/RU in solar energy development (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises due to solar energy developments	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Surface disturbance	Loss of shelter and breeding sites	Restore Habitat (2.6)	habitat in conservation status and location of land protected	Decreased area of surface disturbance within each CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Surface disturbance	Nutritional compromise	Restore Habitat (2.6)	habitat in conservation status and location of land protected	Decreased area of surface disturbance within each CHU/DWMA/RU	options; Plant species composition, species richness, or % cover of invasive	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Tourism & Recreation Sites	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing caused by tourism and rec sites	Decreased number/area of tourism/rec sites within CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to tourism/rec sites	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Tourism & Recreation Sites	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	Decreased number/area of tourism/rec sites within CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due to tourism/rec sites	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Tourism & Recreation Sites	Habitat Loss	Restore Habitat (2.6)	Area and location of reclaimed small-scale development sites	Decreased number/area of tourism/rec sites within CHU/DWMA/RU	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Toxicants	Toxicosis	Restore habitat (toxicants/unexploded ordinance)	Area and location of toxicant/unexploded ordinance clean-ups	toxic chemical releases and increased toxic waste management activities within each CHU/DWMA/RU	Decreased incidence of trauma to live tortoises due toxicants	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Unauthorized Release or Escape of Captive Tortoises to the Wild	Altered behavior	Environmental Education (2.3)	environmental education activities undertaken to counter disruption of social structure caused by release of captive	Decreased measure of number of unauthorized release or escape of captive tortoises to the wild	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Release or Escape of Captive Tortoises to the	Altered behavior	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to release of captive tortoise to the wild	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Release or Escape of Captive Tortoises to the Wild	Altered behavior	Install and maintain human barriers (preserves) (2.7)	Length and location of human barriers around preserves	Decreased measure of number of unauthorized release or escape of captive tortoises to the wild (around preserves)	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Release or Escape of Captive Tortoises to the Wild	Altered behavior	Install and maintain human barriers (wildland-urban interface) (2.7)	Length and location of human barriers at the wildland-urban interface	Decreased measure of number of unauthorized release or escape of captive tortoises to the wild (at the wildland-urban interface)	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Unauthorized Release or Escape of Captive Tortoises to the Wild	Genetic contamination	Environmental Education (2.3)	environmental education activities undertaken to counter genetic contamination caused by release of	Decreased measure of number of unauthorized release or escape of captive tortoises to the wild	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Release or Escape of Captive Tortoises to the	Genetic contamination	Increase law enforcement (2.4)	Total number and location of LE	Decreased number of encounters with the public related to release of captive tortoise to the wild	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Release or Escape of Captive Tortoises to the Wild	Genetic contamination	Install and maintain human barriers (preserves) (2.7)	Length and location of human barriers around preserves	Decreased measure of number of unauthorized release or escape of captive tortoises to the wild (around preserves)	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Release or Escape of Captive Tortoises to the Wild	Genetic contamination	Install and maintain human barriers (wildland-urban interface) (2.7)	Length and location of human barriers at the wildland-urban interface	Decreased measure of number of unauthorized release or escape of captive tortoises to the wild (at the wildland-urban interface)	Decreased incidence of captive releases/escapes in a particular area	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Unpaved Roads	Loss of shelter and breeding sites	Restore Habitat (2.6)	habitat restoration has taken place on former unpaved roads	Decreased area/length of unpaved roads within the CHU/DWMA/RU	Increased area with suitable burrows, caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Unpaved Roads	and breeding sites	mulching-roads) (2.3.6)	Locations of vertical mulching	unpaved roads within the CHU/DWMA/RU	caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Unpaved Roads	and breeding sites	Sign Designated Routes (2.1.8)	Locations of signed designated routes	unpaved roads within the CHU/DWMA/RU	caliche caves, and/or sufficient vegetation for shelter	Condition of desert tortoise habitat is demonstrably improving
Urbanization	Crushing	Environmental Education (2.3)	environmental education activities undertaken to counter crushing due to	Decreased area of urban development within each CHU/DWMA/RU	Decreased incidence of trauma to live tortoises within the wildland-urban interface	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

Utility Lines and Corridors	Habitat Loss	Restore Habitat (2.6)	Area and location of restoration	Decreased length/area of utility lines and corridors within the CHU/DWMA/RU	Increased area of intact habitat, Average size of contiguous habitat patch per recovery unit, Average edge to area ratio for habitat patches	Enough habitat within each RU is protected and managed to support long-term viability of population; increased population densities
Wild Horse & Burros	Crushing	Minimize wild horse and burro impacts (2.15)	of activities to minimize wild horse and burro impacts to habitat were minimized	Number of wild horses and burros removed	Decreased incidence of trauma to live tortoises due to wild horses and burros	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Wild Horse & Burros	Entrapment/burial	Minimize wild horse and burro impacts (2.15)	of activities to minimize wild horse and burro impacts to habitat were minimized	Number of wild horses and burros removed	Decreased incidence of trauma to live tortoises due to wild horses and burros	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities
Wind Energy Development	Crushing	Install and maintain tortoise barrier fencing (2.5, 2.7)	Length and location of tortoise fence installed	CHU/DWMA/RU in wind energy development (unfenced); increased area fenced	Decreased incidence of trauma to live tortoises due to wind energy developments	Rates of population change (λ) are increasing (i.e., λ > 1); increased population densities

APPENDIX D:
Elasticity Calculation

Our objective was to quantify the relative importance (i.e., weights) of different demographic rates to the population growth of the Mojave Desert Tortoises so that the effects of changes in threats on demographic rates and thus population growth can be assessed within the framework of the Spatial Decision Support System. Specifically, we were interested in the weights associated with the demographic rates of two stage classes of tortoises: reproductive ($\geq$ 180 mm MCL) and non-reproductive (< 180 mm MCL), hereafter adults and juveniles, respectively. We used elasticity values as weights because they indicate the relative importance of each demographic rate to annual population growth (λ). Elasticities are calculated from population projection matrices constructed from the demographic rates as the proportional change in λ (i.e., the dominant eigenvalue of the matrix and the annual growth rate at stable stage distribution) given a proportional change (1%) in a single demographic rate when all other demographic rates are held constant.

Doak et al. (1994) had previously calculated elasticities for the demographic rates of a population of Desert Tortoises in the Western Mojave Desert. In their analysis, they divided the population into 8 life stages, consisting of one age class (Yearling) and seven size classes (Juvenile 1, Juvenile 2, Immature 1, Immature 2, Subadult, Adult 1, and Adult 2). Sufficient data were available to calculate survival and growth rates (Table 1), but reproductive data were sparse and estimates of fertility were unreliable. To circumvent this deficiency, Doak et al. (1994) created fertility rates for four scenarios that spanned a range of reproduction levels: "low", "medium-low", "medium-high", and "high" reproduction (Table 1). Using the survival and growth rates and each set of fertility rates, they constructed four eight-stage population projection matrices from which they derived elasticities for each demographic rate (Table 2). We re-created their analyses to obtain the elasticities for each of the eight stage classes under the "medium-low" and "medium-high" reproduction levels. For each reproduction level, we summed the elasticity values of each demographic rate over the first five stage classes to obtain weights for juveniles and over the last three stage classes to obtain adult weights and then we averaged the sums of each level (Table 3). The resulting elasticities indicated that survival rates of adults and juveniles had considerably more effect on population growth (0.55 and 0.43, respectively) than did fertility (0.04) or the rate with which tortoises transitioned through juvenile (0.01) and adult (0.07) stages.

Because we were ultimately interested in a two-stage division of the population, we also derived the weights directly from two-stage matrices (Table 4). This approach required the preliminary step of combining the demographic rates into juvenile and adult stages. We calculated survival and growth rates for juvenile and adult classes using both the geometric mean and the product of the rates of the five smallest and three largest stages from Doak et al. (1994) because the probabilities of survival and growth through the consecutive classes were multiplicative. In contrast, we calculated adult fertility rates using the arithmetic mean of the three largest stages because fertility, measured as the number of yearlings produced per female, was additive. We used the combination of survival and growth rates that yielded values of λ that were most similar to those obtained by Doak et al. (1994) (λ = 0.919 for "medium-low" and λ = 0.958 for "medium-high" reproduction). The combination of the geometric mean of survival rates and product of growth rates yielded values of λ that most closely met this criterion (Table 5). We obtained the elasticies from the two-stage matrices (Table 4) based on the "medium-low" and "medium-high" reproduction levels and averaged the elasticities across reproduction levels to get the weights for adult and juvenile demographic rates (Table 3). The average values were 0.87 and 0.12 for adult and juvenile survival, respectively, and 0.02 for fertility and juvenile growth. Adult growth was unimportant.

Table 1. Annual survival and growth rates of 1 age and 7 size classes of Western Mojave desert tortoises and reproductive rates under four different scenarios.

Class name	Size Class	Mean Survival	SD Survival	Mean Growth	SD Growth	Low Reproduction	Medium-low Reproduction	Medium-high Reproduction	High Reproduction
Yearling	0	0.716	0.232	1	0	0	0	0	0
Juvenile 1	1	0.716	0.232	0.208	0.268	0	0	0	0
Juvenile 2	2	0.716	0.232	0.208	0.268	0	0	0	0
Immature 1	3	0.839	0.176	0.28	0.158	0	0	0	0
Immature 2	4	0.785	0.147	0.287	0.261	0	0	0	0
Subadult	5	0.927	0.071	0.269	0.187	0.042	0.42	1.3	2.22
Adult 1	6	0.867	0.129	0.018	0.037	0.069	0.69	1.98	3.38
Adult 2	7	0.86	0.123	0	0	0.069	0.69	2.57	4.38

Table 2. Definition of stage-structured population matrix elements for the desert tortoise using the fertility (f_i)[a], survival (s_i), and growth (g_i)[b] rates and assuming a pre-breeding census.

		Size class in year t							
Class Name	Size class in year t+1	0	1	2	3	4	5	6	7
Yearling	0						f_5	f_6	f_7
Juvenile 1	1	s_2	$s_2(1\text{-}g_2)$						
Juvenile 2	2		$s_2\ g_2$	$s_2(1\text{-}g_2)$					
Immature 1	3			s_2g_2	$s_3(1\text{-}g_3)$				
Immature 2	4				s_3g_3	$s_4(1\text{-}g_4)$			
Subadult	5					s_4g_4	$s_5(1\text{-}g_5)$		
Adult 1	6						s_5g_5	$s_6(1\text{-}g_6)$	
Adult 2	7							$s_6\ g_6$	s_7

[a] Fertility (f_i) is measured as the number of yearling females at the next census produced by a female at the current census (i.e., survival over the first year of life is included).

[b] Growth rates(g_i) is the annual probability of transitioning from class *i* to class *i* + 1.

Table 3. Elasticity values for adult and juvenile demographic rates under scenarios of medium-low and medium-high reproduction.

8 Size Classes[a]					
Reproduction Level	Juvenile Survival	Adult Survival	Fertility	Juvenile Growth	Adult Growth
Medium-Low	0.385	0.609	0.033	0.058	0.005
Medium-High	0.479	0.492	0.043	0.087	0.004
Average	0.432	0.550	0.038	0.072	0.005

2 Size Classes[b]					
Reproduction Level	Juvenile Survival	Adult Survival	Fertility	Juvenile Growth	Adult Growth
Medium-Low	0.073	0.923	0.011	0.011	0.000
Medium High	0.163	0.819	0.028	0.028	0.000
Average	0.118	0.871	0.020	0.020	0.000

[a] Juvenile elasticity values were calculated by summing elasticities of Yearling – Immature 2 classes derived from the 8-stage matrix and adult elasticity values for adults by summing of Subadult – Adult 2 classes.

[b] Elasticities for juveniles and adults were calculated directly from a two-stage matrix.

Table 4. Definition of stage-structured population matrix elements for the desert tortoise from the fertility (f_i)[a], survival (s_i), and growth rates (g_i) assuming a pre-breeding census.

		Size class in year t	
Class Name	Size class in year t+1	0	1
Juvenile	0	$s_0(1-g_0)$	f_1
Adult	1	$s_0 g_0$	s_1

Table 5. Annual survival, growth, and reproductive rates of two stage classes of Western Mojave desert tortoises that have been derived from the demographic rates of eight classes (Doak et al. 1994) using either the geometric mean or the product for survival and growth rates and the arithmetic mean for reproductive rates.

Survival - Geometric Mean, Growth - Product, Reproduction - Arithmetic Mean

Class Name	Size Class	Mean Survival	Mean Growth	Low Reproduction	Medium-low Reproduction	Medium-high Reproduction	High Reproduction
Juvenile	0	0.753	0.003	0	0	0	0
Adult	1	0.884	0	0.060	0.600	1.950	3.327
Lambda					0.895	0.915	

Survival - Product, Growth - Product, Reproduction - Arithmetic Mean

Class Name	Size Class	Mean Survival	Mean Growth	Low Reproduction	Medium-low Reproduction	Medium-high Reproduction	High Reproduction
Juvenile	0	0.242	0.003	0	0	0	0
Adult	1	0.691	0	0.060	0.600	1.950	3.327
Lambda					0.692	0.695	

Survival - Geometric Mean, Growth - Geometric Mean, Reproduction - Arithmetic Mean

Class Name	Size Class	Mean Survival	Mean Growth	Low Reproduction	Medium-low Reproduction	Medium-high Reproduction	High Reproduction
Juvenile	0	0.753	0.243	0	0	0	0
Adult	1	0.884	0	0.06	0.6	1.95	3.327
Lambda					1.094	1.344	

APPENDIX E:
Full Data Inventory for Desert Tortoise SDSS (2011)

Threat Type	Dataset Name	Description	Data Source	Year
Agriculture	NLCD_2006_Swclip	Pasture/Hay and Cultivated Crops classifications from the raster file for land cover classification.	U.S. Geological Survey	2006
Air Pollution	CA_NitrogenDep	Provides a geography of annual nitrogen deposition throughout most of the state of California including locations where there are no measurement data. Supports study of effect of anthropogenic nitrogen on the structure and function of terrestrial ecosystems.	University of California - Riverside	2007
Altered hydrology	ALTEREDHYDRO	Altered hydrology is the modification of the occurrence, distribution, and movement of water, such that natural water transportation, storage and evaporation processes are affected. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Historical Fire, Paved Roads, Storms and Flooding, and Surface disturbance.	The Redlands Institute, University of Redlands	2011
Aqueducts	SW_AqueductCanals	Aqueducts & Canals in the Southwest US	ESRI® Data & Maps 2010	2011
Captive Release or Escape	CAPTIVERELEASE	Unauthorized Release or Escape of Captive Tortoises to the Wild is the release of captive-reared and/or wild-caught tortoises that have been in captivity. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. This threat is derived from Human Access.	The Redlands Institute, University of Redlands	2011

Coyotes & Feral Dogs	COYOTEFERALDOGS	Predators (non-raven) are coyotes, kit foxes, ground squirrels, red-tailed hawks, and other mammalian and avian species; to the extent any of these are subsidized by human activities, the elevated levels of predation are a stressor on desert tortoise populations. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Aqueducts, Drought, Garbage and Dumping, Landfills, Military Operations, Motor Vehicles on Paved Roads, Tourism and recreation areas, and Urbanization/Human Development.	The Redlands Institute, University of Redlands	2011

Disease	DISEASE	Harmful pathogens and other microbes that may or may not be endemic to the ecosystem or region, may move through populations naturally, or be directly or indirectly introduced and spread by humans. Upper respiratory tract disease as caused by Mycoplasma spp. is the best known disease pertinent to the desert tortoise; others include herpesvirus and Pasteruela testudinis. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Drought, Unauthorized Release or Escape of Captive Tortoises to the Wild, Toxicants, Unknown Disease Contributors.	The Redlands Institute, University of Redlands	2011
Drought	DROUGHT	Drought is periods in which rainfall falls below the normal range of variation, which can result in desertification and limited water availability. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat has been modeled as a constant across the Mojave Desert due to the lack of data and lack of confidence in the modeling parameters.	The Redlands Institute, University of Redlands	2011

Fire Potential	CA_FIRETHREAT	Fire Threat is a combination of two factors: 1) fire frequency, or the likelihood of a given area burning, and 2) potential fire behavior (hazard). These two factors are combined to create 4 threat classes ranging from moderate to extreme	California Department of Forestry and Fire Protection (FRAP)	2004
Free-roaming Dogs	FOOTPRINTMODEL_DOG	This model is based on how dogs utilize wildlands near human habituation. These predators can have detrimental effects on wildlife populations (Alterio et al. 1998). We based our model on the data collected by Odell and Knight (2001) that investigated habitat utilization of these predators with regard to distance from housing and on the probability for a homeowner to possess a dog.	Steve Hanser and Matthias Leu, USGS-FRESC	2008
Fugitive Dust	FUGITIVEDUST	Fugitive dust is Airborne particulate matter containing toxicants released from anthropogenic sites such as mines, roads, construction, and other disturbances. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Agriculture, Mineral Development, Surface disturbance.	Redlands Institute, University of Redlands	2011

Garbage and Dumping	GARBAGEDUMPING	Garbage and Dumping is refuse resulting from unauthorized dumping and littering or wind-blown accumulation. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Human Access, Landfills, and Non-motorized Recreation data.	The Redlands Institute, University of Redlands	2011
Geothermal Energy Development	SW_GeoPowerPlants	Locations of geothermal power plants as of early 2010	Great Basin Center for Geothermal Energy	2010
Grazing	SW_Grazing_RU	A mosaic of state level data from the four Bureau of Land Management State GIS sites. The grazing allotmentspastures are Federal lands upon which private individuals graze livestock.	U.S. Department of the Interior, Bureau of Land Management	2009
Historical Fire	CA_Fires1878_2008	Perimeters for large wildfires CA, 1878-2008, National Park Service, Bureau of Land Management, and US Forest Service	CAL FIRE	2008
Historical Fire	SW_Fires_2009	Fire History Perimeters 2009	The Geospatial Multi-Agency Coordination Group (GeoMAC)	2009
Historical Fire	SW_Fires_2010	Fire History Perimeters 2010	The Geospatial Multi-Agency Coordination Group (GeoMAC)	2010
Historical Fire	EAFB_HistoricalFires	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Historical Fire	SW_Fires_2011	Fire History Perimeters 2011	The Geospatial Multi-Agency Coordination Group (GeoMAC)	2011
Human Access	Human Use	A model of human use of ecosystems based on compiling estimates of traffic volume, modeling how traffic diffuses across the transportation and the adjacent landscape, and modeling the functional relationship of how use declines with distance (measured by travel time).	The Natural Resource Ecology Laboratory, Colorado State University	2010

Human Access		nate's model	Redlands Institute, University of Redlands	2012
Invasive Plants	FOOTPRINTMODEL_EXOTIC	This model was constructed to model the risk of invasion by exotic plant species.Roads may directly influence exotic plant dispersal via disturbance during road construction or via alterations in soil regimes. Roads may also indirectly facilitate the dispersal of exotic grasses, such as crested wheatgrass (Agropyron cristatum), via human seeding along road verges or in burned areas near roads as a management strategy to curb the establishment of less desirable exotic grass species. The inputs for this model are road type, distance from road, forest - non-forest vegetation, and proximity to rural-urban and agricultural areas.	Steve Hanser and Matthias Leu, USGS-FRESC	2008
Landfills	SW_Landfills_HF	Locations of landfills and waste transfer stations in 11 western states. Data was obtained from state and federal agencies in GIS, tabular, and map format.	USGS-FRESC, Human Footprint	2003
Landfills	WEMO_Landfills	This is a coverage of landfills, sewage ponds, and other unknown raven attractants and subsidies shown in the 1994 DWMA recovery plan from the Fish and Wildlife service. The areas were located by township, range, and section information, and designated from information given in the document.	Redlands Institute, University of Redlands	2003
Landfills	EAFB_BorrowPits	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	ChocMtns_HighExplosiveAreas	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER	Bobby Law, MCAS Yuma, Arizona	2012
Military Operations	SW_MilitaryOwnership2012	Military Installations in the Southwest US	BLM	2012
Military Operations	EAFB_Sidewalks	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	EAFB_RecreationAreas	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	EAFB_TargetAreas	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012

Military Operations	EAFB_HabitatDisturbance	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	EAFB_ExistingStructures	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	EAFB_Airfields	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_DryLakesSprings_offlimits	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_DesertCymopterus_conservation	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_DT_LMMV_conservation	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Slow_Go_slopes	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_No_Go_slopes	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Airfield_ramp	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Airfield_surface	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_CanopyPavilion_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Median_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_PedestrianSidewalk_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Road_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Slab_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Structure_existing	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Vehicle_driveway_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	FtIrwin_Vehicle_parking_area	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	EAFB_BurrowingOwl_conservation	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	EAFB_HeadStart_pens	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Military Operations	MCAGCC_Alt6_ImpactAreas	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		
Mineral Development	CA_AbandonedMines	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER	CA BLM	2007
Mineral Development	CA_ActiveMines	Active Mining Claims in the BLM California Desert District, October 2009	CA BLM	2009
Mineral Development	Moj_Mines_SMARAII	USE FOR ANALYSIS BUT TO NOT POST TO DATA EXPLORER		2012
Mineral Development	Moj_Mines_TOMS			2012

Mineral Development	SW_MineralLocationsDatabase 2012	Contains Mineral resource occurrence data provided in the Mineral Resource Data System (MRDS) of USGS and the Mineral Availability System/Mineral Industry Locator System (MAS/MILS) originated in the U.S. Bureau of Mines, which is now part of USGS, and clipped to the Southwest US.	U.S. Geological Survey	2012
Motor Vehicles Off Route	BLM_RT_co_em_kr_fr	This is the proposed route network published in the West Mojave Plan FEIS, February, 2005, for the Coyote, El Mirage, Kramer, and Fremont subregions.	U.S. Bureau of Land Management, California Desert District	2005
Motor Vehicles Off Route	BLM_RT_NECO	Routes of travel, NECO Plan area	BLM	2000
Motor Vehicles Off Route	BLM_RT_NEMO	This is a line representation of the Routes within the NEMO EIS area. This theme was created specifically for the Bureau of Land Management in the California Desert District.	BLM	2003
Motor Vehicles Off Route	BLM_RT_rtslwm_prop_8587	This is the proposed route network published in the West Mojave Plan FEIS, Nov. 2004, for those areas outside the subregions inventoried in 2002-03	U.S. Bureau of Land Management, California Desert District	2003
Motor Vehicles Off Route	BLM_RT_su_rm_nr_ju	This is the proposed route network published in the West Mojave Plan FEIS, February, 2005, for the Superior, Red Mountain, Newberry-Rodman, and Juniper subregions.	U.S. Bureau of Land Management, California Desert District	2004
Motor Vehicles Off Route	SW_OHV_Areas	The SW_OHV layer is a mosaic of state level data from the four Bureau of Land Management State GIS sites. This data is designed to display the Open/Closed/Limited boundaries of Off Highway Vehicle (OHV) areas.	U.S. Department of the Interior, Bureau of Land Management	2009

Motor Vehicles Off Route	WEMO_OHV_ImpactAreas	Based on a BLM inventory of vehicle based disturbances calculated for the West Mojave Plan; parcels with a higher than average number of vehicle based disturbance that had a higher than average number of TCS as defined above, received a +2; parcels with a higher than average number of vehicle based disturbances but less than the average number of TCS as defined above, received a +1; all other parcels received a zero.	U.S. Bureau of Land Management, California Desert District	2003
Motor Vehicles on Paved Roads	DeathValley_Roads			2012
Motor Vehicles on Paved Roads	EAFB_Transportation	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Motor Vehicles on Paved Roads	FtIrwin_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Motor Vehicles on Paved Roads	MCAGCC_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		
Motor Vehicles on Paved Roads	SW_Roads2010_ESRI	U.S. and Canada Streets Cartographic represents streets, highways, interstate highways, roads with and without limited access, secondary and connecting roads, local and rural roads, roads with special characteristics, access ramps, and ferries within the United States and Canada.	ESRI	2010
Motor Vehicles on Unpaved Roads	BLM_RT_co_em_kr_fr	This is the proposed route network published in the West Mojave Plan FEIS, February, 2005, for the Coyote, El Mirage, Kramer, and Fremont subregions.	U.S. Bureau of Land Management, California Desert District	2005
Motor Vehicles on Unpaved Roads	BLM_RT_NECO	Routes of travel, NECO Plan area	BLM	2000
Motor Vehicles on Unpaved Roads	BLM_RT_NEMO	This is a line representation of the Routes within the NEMO EIS area. This theme was created specifically for the Bureau of Land Management in the California Desert District.	BLM	2003
Motor Vehicles on Unpaved Roads	BLM_RT_rtslwm_prop_8587	This is the proposed route network published in the West Mojave Plan FEIS, Nov. 2004, for those areas outside the subregions inventoried in 2002-03	U.S. Bureau of Land Management, California Desert District	2003

Motor Vehicles on Unpaved Roads	BLM_RT_su_rm_nr_ju	This is the proposed route network published in the West Mojave Plan FEIS, February, 2005, for the Superior, Red Mountain, Newberry-Rodman, and Juniper subregions.	U.S. Bureau of Land Management, California Desert District	2004
Motor Vehicles on Unpaved Roads	DeathValley_Roads			2012
Motor Vehicles on Unpaved Roads	FtIrwin_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Motor Vehicles on unpaved Roads	MCAGCC_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		
Motor Vehicles on Unpaved Roads	SW_Roads2010_ESRI	U.S. and Canada Streets Cartographic represents streets, highways, interstate highways, roads with and without limited access, secondary and connecting roads, local and rural roads, roads with special characteristics, access ramps, and ferries within the United States and Canada.	ESRI	2010
Non-motorized Recreation	MOJ_SmallDevelopment	Small human developments that are disjunct from urban and suburban settings which may impact wildlife and endangered species. Recreation sites from various sources includes Boat Launch, Campground, Campsite, Casino, Country Club, Fishing Dock, Golf Course, Horse Campground, Information Center, Interpretive Trail, Marina, Picnic Area, Ranger Station, Rest Stop, Visitor’s Center.	The MOJ_SmallDevelopment layer is a mosaic of data from GIS files (USGS GNIS and AZ BLM RecreationSites_point.shp) as well as digitized points from the National Park maps (http://www.nps.gov) and Caltrans maps. Added 6 points from the USGS Human Footprint	2009
Oil and Gas Development	CA_Pipelines_Gas	Gas Pipelines in the BLM California Desert District	BLM California Desert District	2009
Oil and Gas Development	CA_Pipelines_Oil	Oil Pipelines in the BLM California Desert District	BLM California Desert District	2009
Oil and Gas Development	SW_OilGas	This shapefile contains information on oil and gas wells drilled in the Great Basin, created for purposes of geothermal exploration. The data collected have varying degrees of accuracy, and come from published and unpublished State sources.	Great Basin Center for Geothermal Energy	2007

Open OHV Area Use	SW_OHV_Areas	The SW_OHV layer is a mosaic of state level data from the four Bureau of Land Management State GIS sites. This data is designed to display the Open/Closed/Limited boundaries of Off Highway Vehicle (OHV) areas.	U.S. Department of the Interior, Bureau of Land Management	2009
Other Disease Contributors	OTHERDISEASECONT	Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat has been modeled as a constant across the Mojave Desert due to the lack of data and lack of confidence in the modeling parameters.	The Redlands Institute, University of Redlands	2011
Paved Roads	DeathValley_Roads			2012
Paved Roads	EAFB_Transportation	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Paved Roads	FtIrwin_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Paved Roads	MCAGCC_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		
Paved Roads	SW_Roads2010_ESRI	U.S. and Canada Streets Cartographic represents streets, highways, interstate highways, roads with and without limited access, secondary and connecting roads, local and rural roads, roads with special characteristics, access ramps, and ferries within the United States and Canada.	ESRI	2010

Potential Conversion	Moj_PotentialConversion	Private lands (non-federal, non-state and non-tribal) within the Mojave (excluding the BCCE). Field 'Within_TCA' was added and calculated 'Y' where private land was within or significantly overlapped the Moj_ConservationAreas: TCA = Y. Field 'Within_Corridor' was added and calculated 'Y' where private land was within or significantly overlapped the LeaseCostCorridor data. Field 'Within_neither' was added and calculated where private land did not overlap either the Least Cost Corridor data or the Moj_ConservationAreas: TCA = Y.	Redlands Institute, University of Redlands	2011
Railroads	SW_Railroad2010_ESRI	U.S. National Transportation Atlas Railroads represents a comprehensive database of the nation's railway system. Includes railway name and type.	ESRI Data & Maps 2010 (Federal Railroad Administration)	2010

Ravens	FOOTPRINTMODEL_CORVID	Model of habitat utilization by synanthropic avian predators: common ravens (Corvus corax), American crows (Corvus brachyrhynchos), and black-billed magpies (Pica hudsonia). The former two species show increasing nation-wide population trends, and common ravens in the Mojave desert have been shown to have detrimental effects on threatened desert tortoise (Gopherus agassizii) populations. Power lines are used by common ravens and other raptors for nesting and as hunting perches. Linear features such as railroads, primary and secondary roads, and irrigation channels often serve as travel routes for these predators, and expand their movements into previously unused regions. Numbers of synanthropic avian predators increase in areas surrounding rural human developments, campgrounds, landfills, roads, rest stops, and agricultural lands because they provide reliable and often highly abundant food sources.	Steve Hanser and Matthias Leu, USGS-FRESC	2008
Shift in Habitat Composition/Location	SHIFTHABITATCOMP	Potential changes in climate may cause or have already caused changes in species composition in desert tortoise habitats and shifts in habitat availability and usage. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat has been modeled as a constant across the Mojave Desert due to the lack of data and lack of confidence in the modeling parameters.	The Redlands Institute, University of Redlands	2011

Solar Energy Development	SW_Existing_SolarSites_JAN2012	Spatial footprint of existing solar energy facilties in Southern California and Southern Nevada within the boudaries of the USFWS Desert Tortoise Recovery Units.	Redlands Institute, University of Redlands	2012
Storms and Flooding	STORMSFLOODING	Storms and flooding is extreme precipitation and/or wind events or major shifts in seasonality of storms. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat has been modeled as a constant across the Mojave Desert due to the lack of data and lack of confidence in the modeling parameters.	The Redlands Institute, University of Redlands	2011

Surface disturbance	SURFACEDISTURBANCE	Surface disturbance is the Disruption or removal of surface soil and/or vegetation. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Agriculture,Geothermal Energy Development, Grazing, Military Operations, Mineral Development, Motor Vehicles Off Route, Motor Vehicles on Unpaved Roads, Non-motorized Recreation, OHV Events, Oil and Gas Development, Open OHV area use, Paved Roads, Railroads, Solar Energy Development, Tourism and recreation areas, Unpaved Roads, Urbanization/Human Development, Utility Lines and Corridors, Wild Horse & Burros, and Wind Energy Development.	The Redlands Institute, University of Redlands	2011
Temperature Extremes	TEMPEXTREMES	Temperature extremes is periods in which temperatures exceed or go below the normal range of variation, including heat waves and cold spells. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat has been modeled as a constant across the Mojave Desert due to the lack of data and lack of confidence in the modeling parameters.	The Redlands Institute, University of Redlands	2011

Tourism and recreation areas	MOJ_SmallDevelopment	Small human developments that are disjunct from urban and suburban settings which may impact wildlife and endangered species. Recreation sites from various sources includes Boat Launch, Campground, Campsite, Casino, Country Club, Fishing Dock, Golf Course, Horse Campground, Information Center, Interpretive Trail, Marina, Picnic Area, Ranger Station, Rest Stop, Visitor's Center.	The MOJ_SmallDevelopment layer is a mosaic of data from GIS files (USGS GNIS and AZ BLM RecreationSites_point.shp) as well as digitized points from the National Park maps (http://www.nps.gov) and Caltrans maps. Added 6 points from the USGS Human Footprint	2009. Updated 5-28-12
Tourism and recreation areas	SW_Airports	Airport features Southwestern United States.	ESRI® Data & Maps	2009
Toxicants	TOXICANTS	Toxicants are the air- and water-borne toxic substances from mine tailings, illegal dumping of hazardous wastes, garbage/litter, and toxic spills. Even small changes in the landscape can affect the habitat of the Mojave Desert Tortoise (Gopherus agassizii), a federally listed threatened species, and lead to population decline. Where no direct data is available, we model the threat by performing weighted overlays. This threat is derived from Garbage and Dumping, Landfills, Military Operations, Mineral Development, Motor Vehicles Off Route, Motor Vehicles on Paved Roads, Motor Vehicles on Unpaved Roads, OHV events, Oil and Gas Development, Open OHV area use, Paved Roads, Solar Energy Development, and Urbanization/Human Development.	The Redlands Institute, University of Redlands	2011
Unpaved Roads	BLM_RT_co_em_kr_fr	This is the proposed route network published in the West Mojave Plan FEIS, February, 2005, for the Coyote, El Mirage, Kramer, and Fremont subregions.	U.S. Bureau of Land Management, California Desert District	2005

Unpaved Roads	BLM_RT_NECO	Routes of travel, NECO Plan area	BLM	2000
Unpaved Roads	BLM_RT_NEMO	This is a line representation of the Routes within the NEMO EIS area. This theme was created specifically for the Bureau of Land Management in the California Desert District.	BLM	2003
Unpaved Roads	BLM_RT_rtslwm_prop_8587	This is the proposed route network published in the West Mojave Plan FEIS, Nov. 2004, for those areas outside the subregions inventoried in 2002-03	U.S. Bureau of Land Management, California Desert District	2003
Unpaved Roads	BLM_RT_su_rm_nr_ju	This is the proposed route network published in the West Mojave Plan FEIS, February, 2005, for the Superior, Red Mountain, Newberry-Rodman, and Juniper subregions.	U.S. Bureau of Land Management, California Desert District	2004
Unpaved Roads	DeathValley_Roads			2012
Unpaved Roads	FtIrwin_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Unpaved Roads	MCAGCC_Roads	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		
Unpaved Roads	SW_Roads2010_ESRI_RU	U.S. and Canada Streets Cartographic represents streets, highways, interstate highways, roads with and without limited access, secondary and connecting roads, local and rural roads, roads with special characteristics, access ramps, and ferries within the United States and Canada.	ESRI	2010
Urbanization	NLCD2006_LANDCOVER	Updated circa 2006 land cover layer (raster) for the conterminous United States	U.S. Geological Survey	2006
Utility Lines and Corridors	CA_UtilityCorridors	Location of Utility Corridors in the California Desert District	CA BLM, CDD, Larry LaPre	1999
Utility Lines and Corridors	CA_UtilityLines	Location of Utility Lines in the California Desert District	BLM CDCA	unknown
Utility Lines and Corridors	EAFB_TransmissionLines	USE FOR ANALYSIS. DO NOT POST TO DATA EXPLORER		2012
Wild Horse and Burros	DeathValley_WildHorseBurro			2012

Wild Horse and Burros	SW_HerdManagementAreas2009	A mosaic of state level data from four Bureau of Land Management State GIS sites. A Herd Management Area" is defined as "A herd area identified in an approved land use plan where wild horses and burros will be maintain and managed."	U.S. Department of the Interior, Bureau of Land Management	2009
Wind Energy Development	Moj_WindFarms_March2012			

Recovery Action	Dataset Name	Description	Data Source	Year
Install and maintain tortoise barrier fencing	Moj_RA_TortoiseFencing	A compilation of known AZ, NV, CA, and UT desert tortoise fencing.	Jill S. Heaton, University of Nevada, Reno	2009
Install and maintain human barriers (wildland-urban interface)	Moj_RA_TortoiseFencing			
Install and maintain human barriers (preserves)	Moj_RA_TortoiseFencing			
Environmental Education	Moj_RA_EnvironmentalEducation_line			
Environmental Education	Moj_RA_EnvironmentalEducation			
Remove grazing (close allotments)	SW_Grazing_RU	A mosaic of state level data from the four Bureau of Land Management State GIS sites. The grazing allotmentspastures are Federal lands upon which private individuals graze livestock.	U.S. Department of the Interior, Bureau of Land Management	
Land Aquisition	TWC_DesertAcquisitions	Wildlands Conservancy Desert Acquisitions representing the various land acquisition phases since 1999. Includeds pending residual Catellus land transfer.	The Wildlands Conservancy	2009
Land Aquisition	DTPC_AcquisitionParcels		Mary Kotschwar, Desert Tortoise Preserve Committee, Inc. 5-9-12	2011
Land Aquisition	CA_BLM_Aquisitions20120316			
Restore Habitat	Moj_RA_RestoreHabitat_line			
Restore roads (vertical mulching-roads)	Moj_RA_VertMulchPoints			
Sign Designated Routes	Moj_RA_SignDesignatedRoutes	Open Routes signs within the BLM West Mojave Planning Area (WEMO) placed at intersections and end points of BLM designated open routes to estimate the spatial location of already installed "open route" signs	Bureau of Land Management, Barstow Field Office	2011
Sign and fence protected areas	Moj_RA_SignFenceProtectionAreas			
Withdraw mining	Moj_RA_WithdrawMining			2012

Land Aquisition	DFG_AcquisitionParcels	USE BUT DO NOT SHARE OR POST TO DATA EXPLORER. This dataset is intended to provide information on the location of lands owned and/or administered by the Department of Fish and Game and for general conservation planning within the state.	California Department of Fish and Game	2012

APPENDIX F:
ISEGS Impact and Mitigation Report to the California Energy Commission (2011)

SPATIAL DECISION SUPPORT FOR QUANTIFYING IMPACTS AND MITIGATION OPTIONS FOR THE MOJAVE DESERT TORTOISE: ISEGS

Introduction

The U.S. Fish and Wildlife Service's Desert Tortoise Recovery Office and the University of Redlands, Redlands Institute are developing a spatial decision support system that quantifies the impacts of threats to tortoise populations and identifies and prioritizes recovery actions that are most likely to ameliorate those threats (USFWS, 2011. Revised Recovery Plan for the Mojave Population of the Desert Tortoise, *Gopherus agassizii.* U.S. Fish and Wildlife Service, Sacramento CA). The decision support system models the inter-relationships among threats and tortoise population declines (i.e., which threats cause other threats, and how do these threats increase stresses on tortoise population demographic parameters) and recovery action-tortoise population relationships (i.e., what are the most appropriate actions given a set of population stresses faced by the species?). We characterize risk as the aggregate sum of all stresses on population change. The system relies primarily on GIS data of the spatial extent of threats (i.e., where threats occur geographically) to calculate how changes in threats contribute to changes in risk to tortoise populations utilizing a standard conservation lexicon (Salafsky et al., 2008. Conservation Biology 22:897-911).

Changes in risk to the desert tortoise can come in the form of threat increase (e.g. installation of a large-scale solar project within tortoise habitat) or threat decrease (e.g. undertaking a suite of recovery actions within tortoise habitat). The threat-increase calculation includes not only the predicted increases in risk to the tortoise population from immediate habitat loss and population fragmentation, it also includes predicted downstream effects of the project, such as an increase in traffic volume, roosting sites for tortoise predators, and risk of fire. The threat-decrease calculation analyzes effects of recovery actions (e.g., habitat restoration, installation of tortoise fencing, land acquisition) to estimate the decrease in risk from each action. The two outputs can then be compared to explore the extent of action required to compensate for increased risk to desert tortoise populations from the large-scale development project.

In the current iteration of the decision support system, all changes in risk are calculated on a relative scale (unit-less), comparable across impacts and actions. In future versions of the system (being developed with funding from a CEC PEIR grant and the California BLM), a more meaningful metric of population change will be used. The results presented here are based on the best modeling and information available at this time. We are improving the underlying models, spatial data, and geoprocessing steps within the system iteratively with each new calculation.

It is important to note that for the estimated increase and decrease in risk to be comparable, the time-scale on which these changes in risk act must be comparable and actions must be fully implemented. For example, if the life of the impact is 30 years, then the life of the mitigation actions must be 30 years. If tortoise fencing along roads is installed as an off-set for the 30-year impact, it must be monitored and maintained for the life of the impact (e.g. 30 years). Further, the predicted benefit of each management action assumes perfect implementation. The long-term costs associated with maintenance and continual implementation of management actions on this time-scale must be factored into the mitigation costs.

Methods

We utilized the August 2011 beta-version of the spatial decision support system to estimate the increase in risk to the desert tortoise resulting from modeled implementation of the proposed Ivanpah Solar Energy Generating Station (ISEGS) solar energy development project (Figure 1) within the study area: Eastern Mojave Desert Tortoise Recovery Unit (USFWS 2011). We then utilized the system to estimate the decrease in risk to the tortoise resulting from modeled implementation of management actions provided to us by the CEC and BLM within the study area (Figure 1).

Impact Calculation:
The footprint of the impact includes:
1) Footprint of the ISEGS project;
2) Yates Wells polygon of completely fenced-in area;
3) New utility line;
4) Colosseum Road: unpaved to paved.

Mitigation Calculation:
1.) Raven control: Decrease predator access to subsidies within the area where the model predicts raven numbers will increase due to ISEGS
2.) Land Acquisition: Habitat compensation of ~8,638 acres of private land near project footprint
3.) Land Acquisition in Wash: State jurisdictional waters mitigation of ~160 acres
4.) Tortoise Fencing: Install/maintain tortoise barrier fencing
 a) singled-sided (northbound) of I-15 from Yates Well Road to Nipton Road
 b) singled-sided (southbound) of I-15 from Yates Well Road to Nipton Road
 c) double-sided for Nipton Road to Nipton (fencing stops at the rail road tracks)
 d) single-sided (south-side) of Goffs Road, from Arrowhead Junction to Goffs
 e) single-sided (north-side) of Goffs Road, from Goffs to Fenner
5.) Kern Pipeline Habitat Restoration: ~5 acres/40-miles of habitat restoration

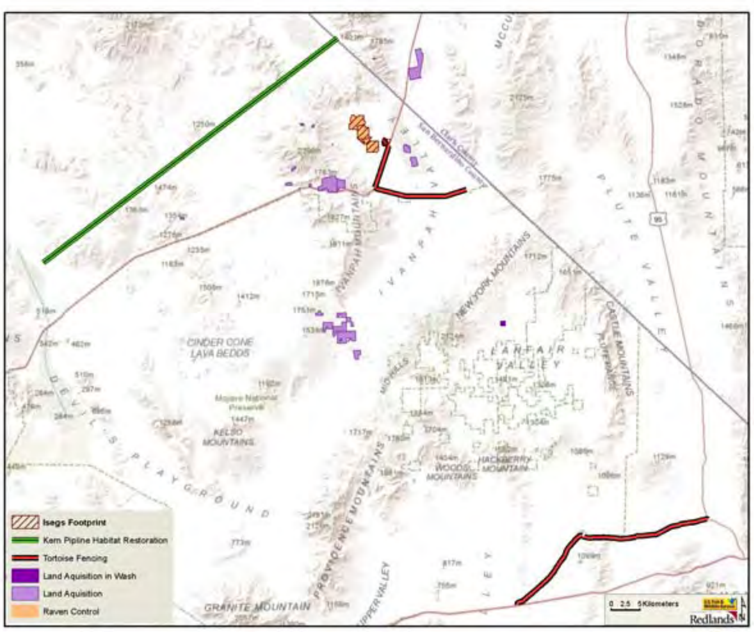


Figure 1. The footprint of ISEGS and proposed desert tortoise mitigation actions.

The steps and component models currently in the system can be summarized as follows:

Threat to Stress to Population Change models

Threat-Stress Interaction Model: estimates contribution of each threat to population stress
Relative Stress Model: estimates contribution of each stress to demographic change parameters
Demographic Impact Model: estimates contributions of demographic change parameters to overall population change

Spatial Threats: utilizes geospatial data to represent where threats occur geographically

Models of the risk to tortoise populations on the ground

Single Risk/Threat Model: combines spatial data with stress to population models to estimate risk to the tortoise from each population stress
Incorporating Probability of Tortoise Presence Model: weights the contribution of stresses to population change by the probability of whether a tortoise is likely to occur at that location on the landscape (our probability of presence layer utilizes the USGS Mojave desert tortoise habitat potential model and incorporates anthropogenic effects with the National Landcover Database's impervious surfaces)

Pre-action Aggregate Risk Model: estimates risk posed to the population by all threats and stresses

Recovery action models

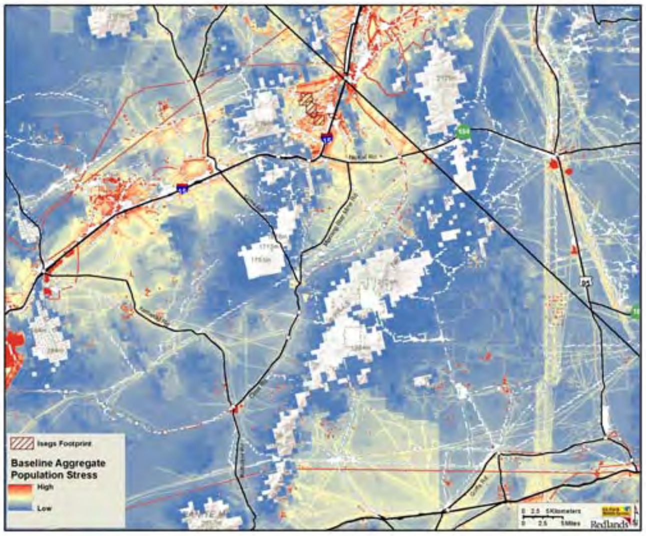
Recovery Action Effectiveness Model: estimates effectiveness of recovery actions in mitigating threat-stress links then combines estimated risk to populations with recovery action effectiveness to estimate change in risk to the tortoise

Results

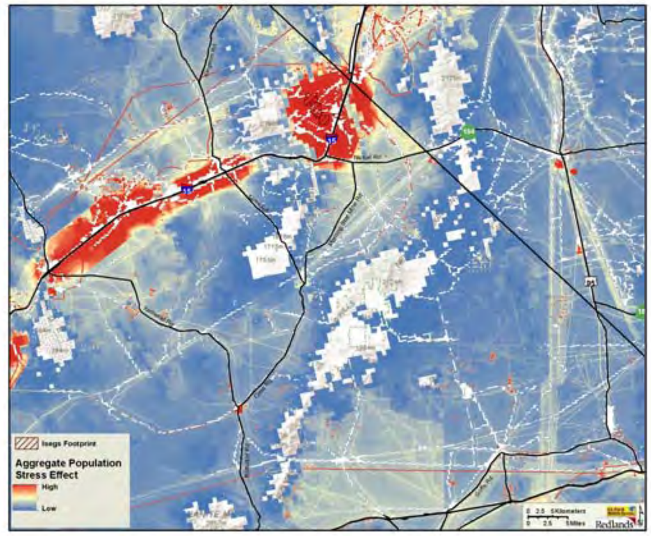
Our analyses resulted in an estimated **4,275-unit increase** in risk to the tortoise from ISEGS (and an estimated **592-unit decrease** in risk from the proposed management actions (Table 1; Figures 2-5). The output numbers calculated are relatively meaningful, and are directly comparable. As a result of implementing both the project and the management actions, across the landscape some individual stresses will be increased, while others will be decreased to create the net change in risk to the tortoise (Figure 6).

Table 1. Estimated risk reduction for each of the proposed management actions

Proposed Management Actions	Decreased Risk to the Tortoise
Install + maintain tortoise fencing (~39 miles)	274
a. Single-sided (northbound) of I-15 from Yates Well Road to Nipton Road = ~5 miles	*21*
b. Single-sided (southbound) of I-15 from Yates Well Road to Nipton Road = ~5 miles	*23*
c. Double-sided from Nipton Road to Nipton = ~10 miles	*74*
d. Single-sided (southside) of Goffs Road, from Arrowhead Junction to Goff = ~13 miles	*93*
e. Single-sided (northside) of Goffs Road, from Goffs to Fenner =~11 miles	*63*
Raven management: “Decrease predator access to human subsidies”	46
Habitat compensation: "Land Acquisition" = ~8,638 acres	208
a. around Cima = ~ 3,648 acres	*151*
b. around Mountain Pass = ~ 2,589 acres	*4*
c. East of Project = ~716 acres	*24*
d. North of State Line = ~ 1,685 acres	*29*
State jurisdictional waters mitigation: "Land Acquisition" = ~160 acres	1
Habitat Restoration: “Restore Habitat”= Kern Pipeline (~5 acres/40-miles)	63
TOTAL	**592**

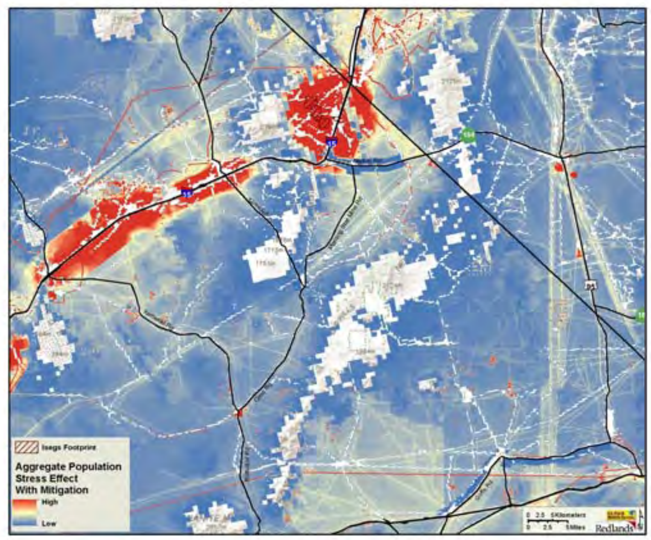


A



B

Figure 2. Treating all stresses on desert tortoise populations as arising from currently observed threats, we can generate an approximate baseline for current risk to the tortoise within the study area (A). We can then estimate the change in risk to the tortoise within the study area that is predicted to result from implementation of proposed ISEGS development project [estimated 4,275-unit increase in risk] (B). We can also estimate the change in risk predicted to result from implementation of proposed mitigation actions [estimated 592-unit decrease in risk] (C). Note that mitigation tends to alleviate stresses to tortoises in sites that are *different* from the project impact area. For example, the only mitigation action which is co-located with the project impact is raven control.



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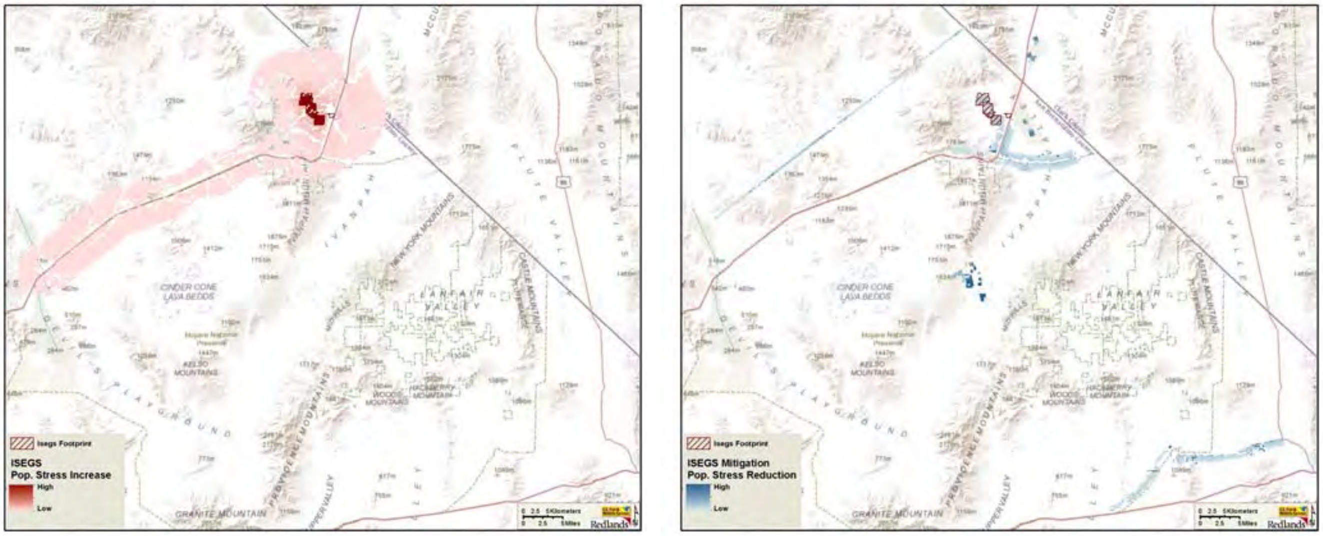

A **B**

Figure 3. For clarity, the change in risk to the tortoise within the study area is depicted here without the baseline stress to the tortoise: (A) estimated increase in risk from implementation of ISEGS (increase in risk of 4,275); and (B) estimated decrease in risk from conducting mitigation actions (decrease in risk of 592). These stresses are calibrated by the probability of tortoise presence (as measured by the USGS habitat potential model minus impervious surfaces) such that a stress where tortoises are more likely to occur contributes more to population change than a stress that occurs where the probability of tortoise presence is low.

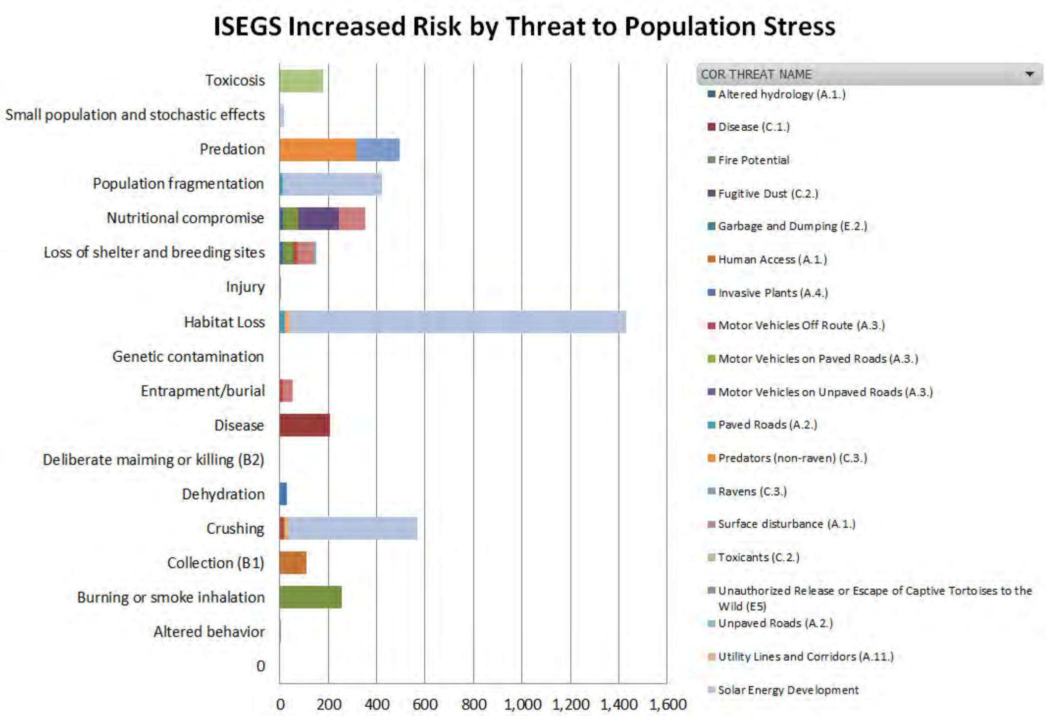

Figure 4. Estimated increase in risk for each tortoise population stress (left column) affected by the threats (right column) predicted to increase due to implementation of ISEGS [estimated 4,275-unit increase in risk].

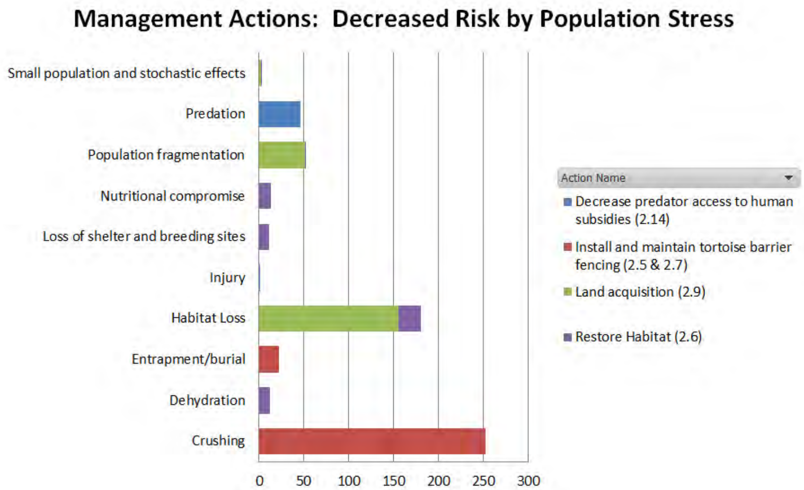

Figure 5. Estimated decrease in risk to the desert tortoise for each threat-population stress relationship predicted to decrease due to implementation of proposed mitigation [estimated 592-unit decrease in risk].

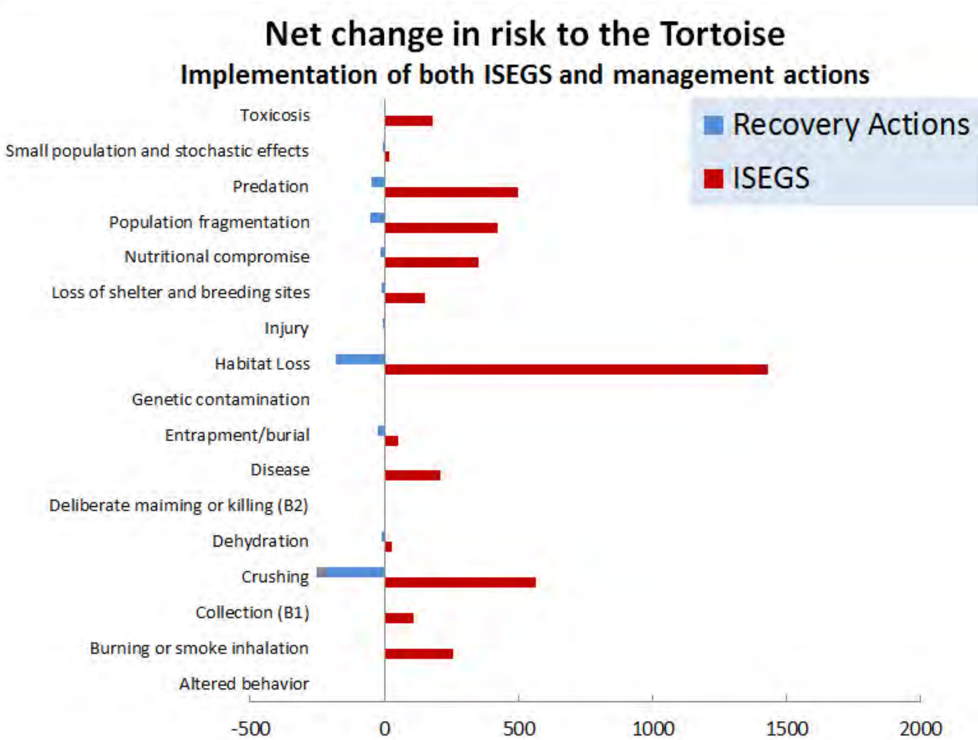

Figure 6. Net change in risk for population stresses affected by ISEGS implementation **and** mitigation actions. Red bars are increase in risk from ISEGS implementation; blue bars are decrease from recovery action implementation. The graph shows that while the purpose of the management actions is to offset the effect of the project, on the landscape some stresses will be increased, while others will be decreased as a result of implementing both the project and the management actions.

For further information: Catherine Darst, USFWS Desert Tortoise Recovery Office, cat_darst@fws.gov

SPATIAL DECISION SUPPORT FOR QUANTIFYING IMPACTS AND MITIGATION OPTIONS FOR THE MOJAVE DESERT TORTOISE: ISEGS

ADDITIONAL MITIGATION CACLULATIONS ADDENDUM

Original Calculations Report: 1 September 2011

Methods

We utilized the August 2011 beta-version of the spatial decision support system to estimate the increase in risk to the desert tortoise resulting from modeled implementation of the proposed Ivanpah Solar Energy Generating Station (ISEGS) solar energy development project (NEW Figure 1). We then utilized the system to estimate the decrease in risk to the tortoise resulting from modeled implementation of management actions provided to us by the CEC and BLM within the study area (NEW Figure 1). Footprints for additional management actions (additional from those quantified in September) were provided by the CEC and CA BLM.

Impact Calculation:
The footprint of the impact includes:
1) Footprint of the ISEGS project;
2) Yates Wells polygon of completely fenced-in area;
3) New utility line;
4) Colosseum Road: unpaved to paved.

Mitigation Calculation:
1.) Raven control: Decrease predator access to subsidies within the area where the model predicts raven numbers will increase due to ISEGS
2.) Land Acquisition: Habitat compensation of ~8,638 acres of private land near project footprint
3.) Land Acquisition in Wash: State jurisdictional waters mitigation of ~160 acres
4.) Tortoise Fencing: Install/maintain tortoise barrier fencing
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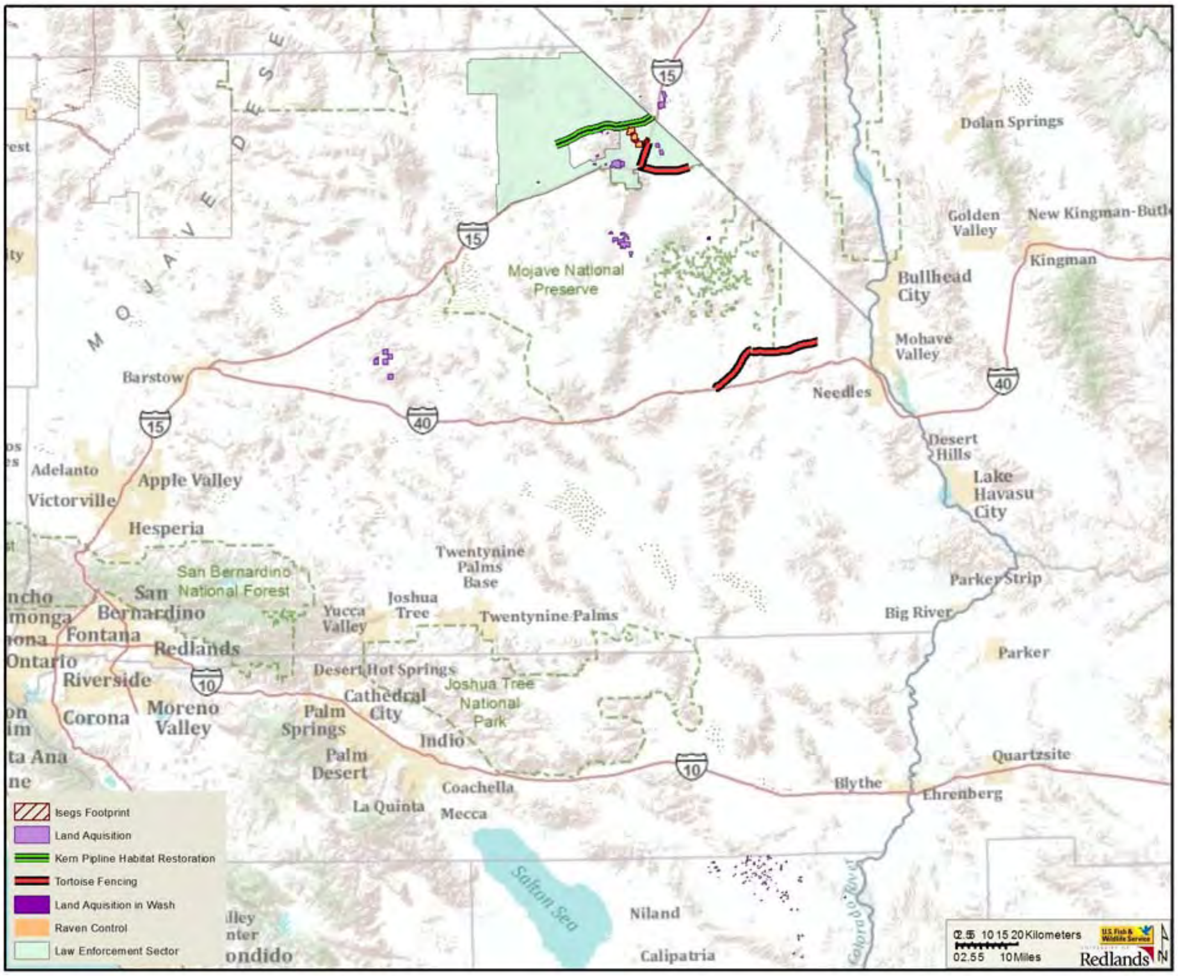
- c) double-sided for Nipton Road to Nipton (fencing stops at the rail road tracks)
- d) single-sided (south-side) of Goffs Road, from Arrowhead Junction to Goffs
- e) single-sided (north-side) of Goffs Road, from Goffs to Fenner

5.) NEW: Kern Pipeline Habitat Restoration: ~20.9 miles of habitat restoration
6.) NEW: Land Acquisition: Habitat compensation of ~5,185 acres within Chuckwalla/Hidden Valley
7.) NEW: Increase law enforcement: additional ranger in BLM Needles Field Office LE Sector 69



NEW Figure 1. The footprint of ISEGS and proposed desert tortoise mitigation actions.

The steps and component models currently in the system can be summarized as follows:

Threat to Stress to Population Change models

Threat-Stress Interaction Model: estimates contribution of each threat to population stress
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Pre-action Aggregate Risk Model: estimates risk posed to the population by all threats and stresses

Recovery action models

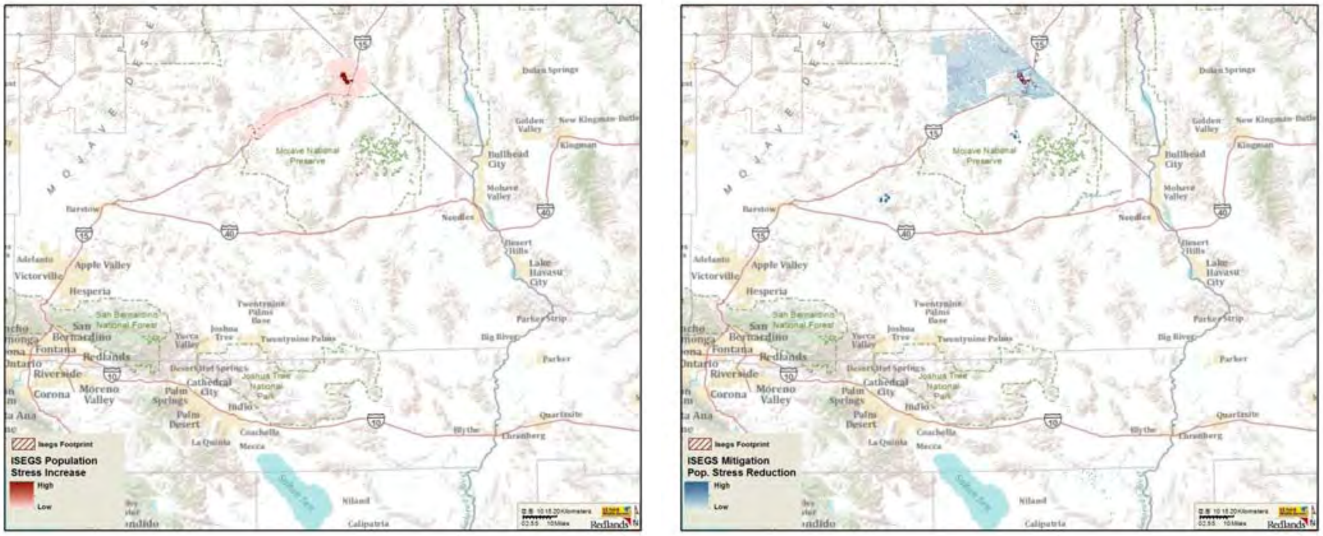
Recovery Action Effectiveness Model: estimates effectiveness of recovery actions in mitigating threat-stress links then combines estimated risk to populations with recovery action effectiveness to estimate change in risk to the tortoise

Results

Our analyses resulted in an estimated **4,275-unit increase** in risk to the tortoise from ISEGS (and an estimated NEW **2,015-unit decrease** in risk from the proposed management actions (NEW Table 1; NEW Figure 2). The output numbers calculated are relatively meaningful, and are directly comparable. As a result of implementing both the project and the management actions, across the landscape some individual stresses will be increased, while others will be decreased to create the net change in risk to the tortoise.

NEW **Table 1.** Estimated risk reduction for each of the proposed management actions

Proposed Management Actions	Decreased Risk to the Tortoise
Install + maintain tortoise fencing (~50 miles)	274
a. Single-sided (northbound) of I-15 from Yates Well Road to Nipton Road = ~5 miles	*21*
b. Single-sided (southbound) of I-15 from Yates Well Road to Nipton Road = ~5 miles	*23*
c. Double-sided from Nipton Road to Nipton = ~10 miles each side	*74*
d. Single-sided (southside) of Goffs Road, from Arrowhead Junction to Goff = ~13 miles	*93*
e. Single-sided (northside) of Goffs Road, from Goffs to Fenner =~11 miles	*63*
Raven management: "Decrease predator access to human subsidies"	46
Habitat compensation: "Land Acquisition" = ~8,638 acres	208
a. around Cima = ~ 3,648 acres	*151*
b. around Mountain Pass = ~ 2,589 acres	*4*
c. East of Project = ~716 acres	*24*
d. North of State Line = ~ 1,685 acres	*29*
State jurisdictional waters mitigation: "Land Acquisition" = ~160 acres	1
NEW Habitat Restoration: "Restore Habitat"= Kern Pipeline: ~20.9 miles)	49
NEW Habitat compensation: "Land Acquisition" = ~5, 185 acres	498
e. Chuckwalla113 8411 = ~ 1,083 acres	*152*
f. Exhibit A Chuckwalla 47 = ~ 774 acres	*99*
g. Hidden Valley = ~3,329 acres	*247*
NEW Increase law enforcement: additional ranger in BLM Needles Field Office LE Sector 69	939
NEW **TOTAL**	**2,015**



A B

NEW **Figure 2.** For clarity, the change in risk to the tortoise within the study area is depicted here without the baseline stress to the tortoise: (A) estimated increase in risk from implementation of ISEGS (increase in risk of 4,275); and (B) estimated decrease in risk from conducting mitigation actions (decrease in risk of 2,015). These stresses are calibrated by the probability of tortoise presence (as measured by the USGS habitat potential model minus impervious surfaces) such that a stress where tortoises are more likely to occur contributes more to population change than a stress that occurs where the probability of tortoise presence is low.

For further information: Catherine Darst, USFWS Desert Tortoise Recovery Office, cat_darst@fws.gov

SPATIAL DECISION SUPPORT FOR QUANTIFYING IMPACTS AND MITIGATION OPTIONS FOR THE MOJAVE DESERT TORTOISE: ISEGS

ADDITIONAL MITIGATION CACLULATIONS: SECOND ADDENDUM

Original Calculations Report: 1 September 2011
First Addendum: 11 October 2011

Methods

We utilized the August 2011 beta-version of the spatial decision support system to estimate the increase in risk to the desert tortoise resulting from modeled implementation of the proposed Ivanpah Solar Energy Generating Station (ISEGS) solar energy development project (NEW Figure 1). We then utilized the system to estimate the decrease in risk to the tortoise resulting from modeled implementation of management actions provided to us by the CEC and BLM within the study area (NEW Figure 1). Footprints for additional management actions (additional from those quantified in September) were provided by the CEC and CA BLM.

Impact Calculation:
The footprint of the impact includes:
1) Footprint of the ISEGS project;
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3) New utility line;
4) Colosseum Road: unpaved to paved.

Mitigation Calculation:
1.) Raven control: Decrease predator access to subsidies within the area where the model predicts raven numbers will increase due to ISEGS
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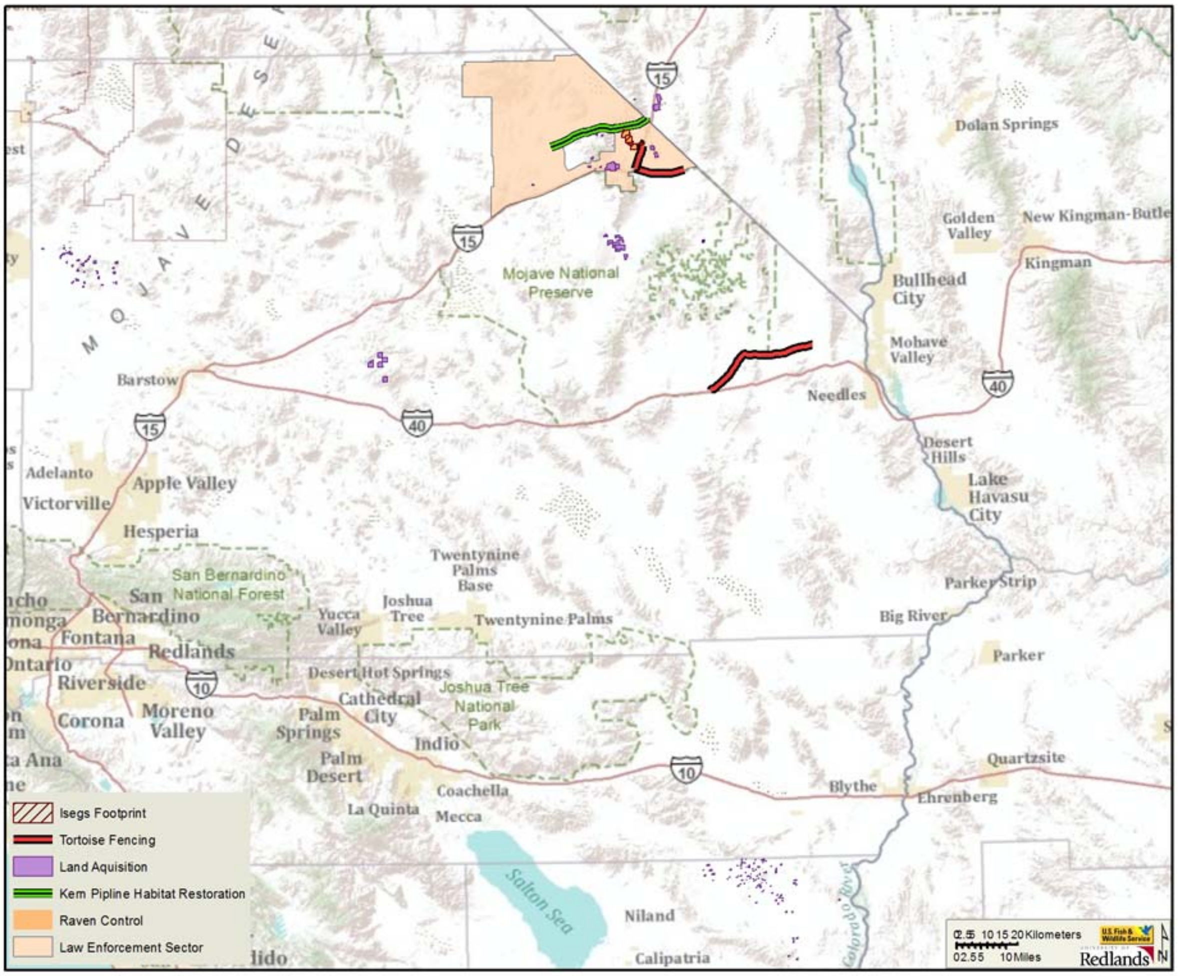
   d) single-sided (south-side) of Goffs Road, from Arrowhead Junction to Goffs
   e) single-sided (north-side) of Goffs Road, from Goffs to Fenner
5.) Kern Pipeline Habitat Restoration: ~20.9 miles of habitat restoration
6.) Land Acquisition: Habitat compensation of ~5,185 acres within Chuckwalla/Hidden Valley
7.) Increase law enforcement: additional ranger in BLM Needles Field Office LE Sector 69
8.) NEW: Land Acquisition: Habitat compensation of ~3,000 acres within Fremont-Kramer



NEW **Figure 1.** The footprint of ISEGS and proposed desert tortoise mitigation actions.

The steps and component models currently in the system can be summarized as follows:

Threat to Stress to Population Change models

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Pre-action Aggregate Risk Model: estimates risk posed to the population by all threats and stresses

Recovery action models

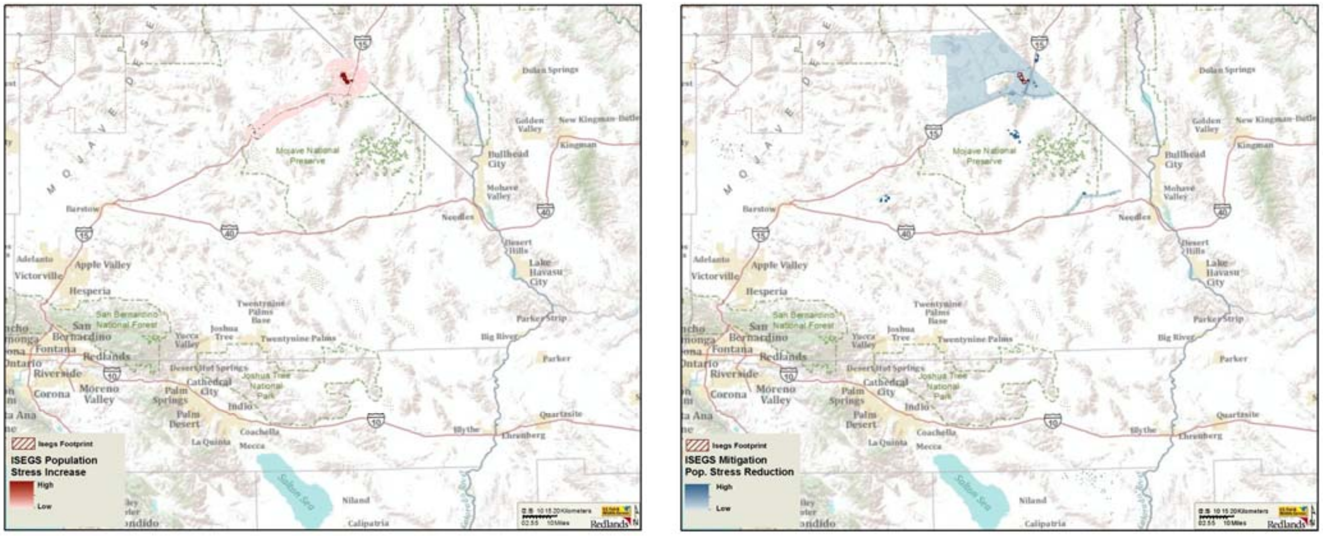
Recovery Action Effectiveness Model: estimates effectiveness of recovery actions in mitigating threat-stress links then combines estimated risk to populations with recovery action effectiveness to estimate change in risk to the tortoise

Results

Our analyses resulted in an estimated **4,275-unit increase** in risk to the tortoise from ISEGS (and an estimated NEW **2,355-unit decrease** in risk from the proposed management actions (NEW Table 1; NEW Figure 2). The output numbers calculated are relatively meaningful, and are directly comparable. As a result of implementing both the project and the management actions, across the landscape some individual stresses will be increased, while others will be decreased to create the net change in risk to the tortoise.

NEW **Table 1.** Estimated risk reduction for each of the proposed management actions

Proposed Management Actions	Decreased Risk to the Tortoise
Install + maintain tortoise fencing (~50 miles)	274
a. Single-sided (northbound) of I-15 from Yates Well Road to Nipton Road = ~5 miles	*21*
b. Single-sided (southbound) of I-15 from Yates Well Road to Nipton Road = ~5 miles	*23*
c. Double-sided from Nipton Road to Nipton = ~10 miles each side	*74*
d. Single-sided (southside) of Goffs Road, from Arrowhead Junction to Goff = ~13 miles	*93*
e. Single-sided (northside) of Goffs Road, from Goffs to Fenner =~11 miles	*63*
Raven management: "Decrease predator access to human subsidies"	46
Habitat compensation: "Land Acquisition" = ~8,638 acres	208
a. around Cima = ~ 3,648 acres	*151*
b. around Mountain Pass = ~ 2,589 acres	*4*
c. East of Project = ~716 acres	*24*
d. North of State Line = ~ 1,685 acres	*29*
State jurisdictional waters mitigation: "Land Acquisition" = ~160 acres	1
Habitat Restoration: "Restore Habitat"= Kern Pipeline: ~20.9 miles)	49
Habitat compensation: "Land Acquisition" = ~5, 185 acres	498
e. Chuckwalla113 8411 = ~ 1,083 acres	*152*
f. Exhibit A Chuckwalla 47 = ~ 774 acres	*99*
g. Hidden Valley = ~3,329 acres	*247*
Increase law enforcement: additional ranger in BLM Needles Field Office LE Sector 69	939
NEW Habitat compensation: "Land Acquisition" = ~3,00 acres in Fremont-Kramer	340
NEW **TOTAL**	**2,355**



A **B**

NEW **Figure 2.** For clarity, the change in risk to the tortoise within the study area is depicted here without the baseline stress to the tortoise: (A) estimated increase in risk from implementation of ISEGS (increase in risk of 4,275); and (B) estimated decrease in risk from conducting mitigation actions (decrease in risk of 2,355). These stresses are calibrated by the probability of tortoise presence (as measured by the USGS habitat potential model minus impervious surfaces) such that a stress where tortoises are more likely to occur contributes more to population change than a stress that occurs where the probability of tortoise presence is low.

For further information: Catherine Darst, USFWS Desert Tortoise Recovery Office, cat_darst@fws.gov